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AIR WEATHER SERVICE
TECHNICAL REPORT 105-124

1951
ANNUAL REPORT OF TYPHOON
POST-ANALYSIS PROGRAM



AUGUST 1954

HEADQUARTERS
AIR WEATHER SERVICE
WASHINGTON 25, D.C.

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AWS TECHNICAL REPORT
NO. 105-124

AIR WEATHER SERVICE
MILITARY AIR TRANSPORT SERVICE
UNITED STATES AIR FORCE
Washington 25, D. C.

August 1954

FOREWORD

1. Purpose: Air Weather Service Technical Report 105-124 is published for the information and guidance of all concerned.

2. Origin and Scope: This Report was prepared by the Air Weather Service detachment at Guam in response to a directive of Headquarters, Air Weather Service. It was reproduced by Headquarters, 1st Weather Wing, Tokyo, for use of its activities. The present report extracts only the technical part of the original report from Guam, for use of forecasters and research meteorologists.

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1951

ANNUAL REPORT

OF THE

TYPHOON POST ANALYSIS PROGRAM

NORTH PACIFIC
TYPHOON WARNING SERVICE

2143D AIR WEATHER WING

Prepared by
Typhoon Post Analysis Board
Det 15-2, 15th Weather Squadron
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C. Reconnaissance	81	Omitted

INTRODUCTION

The purpose of this report is to provide information concerning the activities of the Typhoon Warning Network during 1951. It is designed to evaluate forecasting techniques, operational activities of the Warning Service, and reconnaissance. The summaries of information are provided to substantiate some of the written material in the report and to provide a compact reference for studying the 1951 season.

The study of forecasting techniques is not treated with the same detail as in the 1949 and 1950 Annual Reports due to shortage of personnel and the belief that most of the "laws" and methods were conclusively treated in the two previous Annual Reports. The 1950 report was compiled by six forecasters from the Center, two observer-draftsmen, and one forecaster from the 54th Reconnaissance Squadron, while this report was compiled by two forecasters from the Center, one observer-draftsman, and one forecaster from the 54th. The discussion of forecasting techniques is limited primarily to extrapolation, climatology, and synoptic analysis because they are the primary "tools" of all the units of the Network.

An attempt has been made to prevent duplication, in this report, of material presented in the 1949 and 1950 reports. All three "annuals" should be used as a single unit for reference or training purposes.

Acknowledgement is made to all units of the Typhoon Warning Service for their outstanding contributions to a successful season and for providing the information for this report.

PART I TECHNICAL

A. FORMATION AND BEHAVIOR

Tropical Meteorology, especially that part pertaining to tropical cyclone formation and behavior, has not as yet reached such an advanced stage that hard and fast rules can be established. There have been many theories proposed to explain and predict these phenomena, which are many times difficult even to describe. To put many of these theories into practice is indeed difficult because of the lack of data. For this same reason, caution should be exercised when applying the various rules, for most are based on an interpretation of these sparse data. Perhaps if the data were more abundant these theories would be less plentiful. Before becoming too involved in tropical forecasting, one should become thoroughly familiar with the excellent work of Dr. C. E. Palmer. His notes on Tropical Meteorology were included in the June 1949, 2143d Air Weather Wing Technical Bulletin. All forecasters can profit by reading these notes.

While the area in which tropical cyclones with surface winds of 45 knots or greater have been initially detected is quite large, as can be seen by inspection of the chart, page 2, almost all of the tropical storms or typhoons which have developed during the past few seasons could be traced back to disturbances which were first detected near Kwajalein. Initially, these disturbances were either easterly waves or vortices, and many times they were of such light intensity that it was not deemed necessary to initiate easterly wave bulletins. It appeared during postanalysis that many of these disturbances developed near Kwajalein. Actually, they may have developed some distance east of that atoll, but data throughout that area are so scarce that it is difficult to specify any small area to the east as a source region.

During 1951, the Easterly Wave Program was of great help in following these disturbances as they progressed westward. This Program can become even more valuable through the full and diligent cooperation of all participating units.

The importance of following these disturbances in the easterlies as they move along the route between Kwajalein and Guam cannot be overemphasized. It is often quite difficult to track easterly waves because of the few reporting stations along this route. Throughout most of the 1951 season, upper air reports from Truk and Ponape came in no more often than twice each day. This is not considered to be adequate to meet the needs of the Typhoon Warning Service. Many times a vortex can pass by one of these stations, and, because of the 12-hour interval between upper air reports, no evidence will be given of its passage.

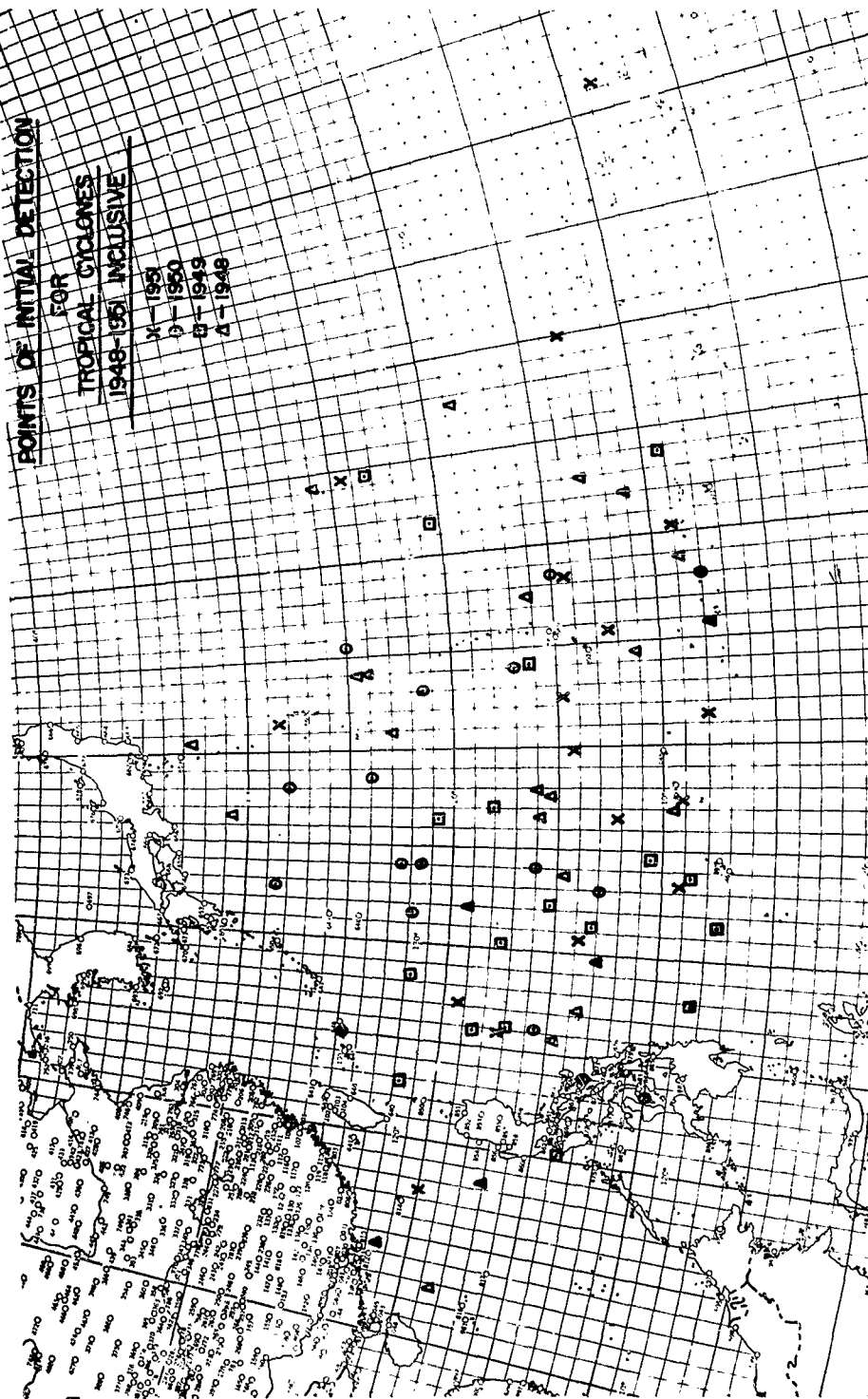
Several indices for detection of easterly waves have been used with relatively good success. Some of these are as follows:

1. Twenty-four hour pressure changes of -1 to -3 millibars.
2. Variation in wind direction from normal easterly flow. Wind usually shifts from northeast through east to southeast in the layer below 700 millibars.

POINTS OF INITIAL DETECTION

FOR
TROPICAL CYCLONES
1948-1951 INCLUSIVE

X - 1951
O - 1950
□ - 1949
Δ - 1948



3. Easterly winds above normal in a small area.
4. Unusual amounts of heavy precipitation persisting for several hours at a given station.
5. Prolonged periods of low ceilings at a given station accompanied by thick middle and high cloudiness.

These indices are included in the 2143d Air Weather Wing Letter 55-134, and have been used throughout the brief history of the Easterly Wave Program in the Pacific.

Let us examine these indices in the light of two years of operation of the Easterly Wave Program. Do 24-hour pressure falls of one to three millibars indicate the approach or passage of an easterly wave? Or, is the presence of one indicated by prolonged, heavy precipitation at a station.

Because of the small space or time variations of pressure, except for diurnal changes, direct analysis of the pressure field in the tropics is of little or no value. It is only in the vicinity of well-developed tropical cyclones that the pressure gradient assumes any significance. However, by analysis of changes in pressure, using 24-hour changes to minimize diurnal variations, detection of slight disturbances is sometimes possible. It has been noticed many times during the existence of the Easterly Wave Program that pressure falls of one to three millibars do not accompany easterly wave passages. At other times falls are noted when the existence of a wave cannot be established. On the other hand, well-defined passages have been noticed with accompanying pressure rises. These passages were indicated by sharp wind shifts, heavy, continuous rain, and thick altostratus overcasts. This criterion of 24-hour pressure falls is by itself neither adequate nor reliable as a means of detecting easterly waves.

Prolonged periods of low ceilings accompanied by both middle and high cloudiness have been observed which cannot be explained adequately by easterly waves or vortices. There have also been periods of above normal rainfall which cannot be explained adequately by these.

Most reliable as a means of detection is analysis of the field of motion. Unfortunately, not enough data are available for complete analysis of this field. Analysis can be performed on the individual time cross-sections, and good results obtained. This analysis can further be augmented by analysis of reports from weather reconnaissance. Many times it is difficult to detect the presence of an easterly wave by this means because wind shifts are often slight, being no more than 10 to 20 degrees. Increases in wind speed are sometimes noted which are not associated with easterly waves or vortices.

Results of nearly two years' operation indicate that none of these criteria, when used alone, is adequate to detect the presence of either an easterly wave or a vortex. Few passages have been observed in which all of these indices were noted. Often no more than one or two are present. Sometimes a passage will be indicated by a good wind shift and above normal precipitation with none of the others. Future research may produce an easier and more reliable means of detecting these disturbances.

but it is unlikely that there will be any time in the near future when the tropical forecaster must not be constantly on the alert and use every scrap of data.

Average speed of movement for these waves has been stated many times as being 10 knots. This is a good approximation and makes computation quite easy. However, this average speed has been, perhaps, overworked in the past, resulting in a loss of confidence in the Program itself. It must be remembered that this speed is an average, and should be treated as such. Speed of movement during the 1951 season has varied from 6 knots to above 16 knots. In the absence of other data, it is a good policy to extrapolate the wave west at the last known average speed. When no average speed can be established, it is then a good idea to extrapolate the wave west at 10 knots until such time as an average speed can be determined from passage at the next island station along the chain. The use of a 10 knot average speed should be used more sparingly than has been the practice.

Most of the waves are ill-defined. There is not, at the present time, any way of determining in advance the weather pattern to be expected. Instances of weather occurring at time of passage have been as prevalent as instances of weather occurring either before or after passage.

After easterly waves and vortices pass Guam, they become increasingly difficult to track. Yap and Koror, the only two regular reporting stations between Guam and the Philippines, are both below 10 degrees north latitude. These stations, as in the case of Truk and Ponape, had no more than two upper air soundings per day throughout most of the 1951 season. During 1950, several of the disturbances recurved, after passing Guam, and intensified. There were no stations northwest of Guam to indicate this, and, as a result, the Network was almost completely dependent upon weather reconnaissance. Also, when the ITO is north of these stations, their reports are of little value in detecting the presence of disturbances. During the 1951 season, Yap and Koror were of more value in tracking easterly waves than during 1950. The main reason for this was that the disturbances moved along farther south during 1951.

As easterly waves approach Guam, they must be watched for signs of intensification. Several rules have been proposed for predicting intensification from vortex to tropical storm or typhoon, and several of these were included in the 1949 and 1950 Annual Reports. An evaluation of these rules is quite difficult because of the lack of data. Most of the time the causes of intensification are obscure. In using these rules caution should be exercised. At the present time, the best policy is to keep each disturbance under constant surveillance and watch for signs of increased wind speed or spreading areas of deteriorating weather.

Once the presence of a well-developed tropical cyclone has been established, the problem of forecasting future movement and intensity arises. The forecasting of intensity is not as difficult as forecasting future movement. Normally, tropical cyclones that attain typhoon intensity do not decrease to a nonhazardous stage until they move over large land masses or become extratropical. In the forecasting of movement many problems arise. Experience during the previous seasons shows that troughs and ridges in the westerlies influence the behavior of tropical cyclones.

Several types of climatological studies have been prepared. One type, showing tracks and average speeds, was included in the 1949 Annual Report. These tracks have been useful during the past two seasons. During 1951, a more detailed study was prepared and distributed to the various network units. Several of these are included in this report, pages 6 through 9. Those included are all that are available at the present time.

As tropical cyclones move west through the lower latitudes, some appear to oscillate slightly rather than to follow a smooth regular path. Several times during the 1951 season this was noticed. For the most part these oscillations appeared when an attempt was made to connect all of the reconnaissance fixes by one line. Admittedly, there are some errors in reconnaissance fixes. During the 1951 season the Reconnaissance Squadrons had many well-experienced personnel. Some of the weather observers and navigators were in their third typhoon season. Several had more than 20 typhoon penetrations. It is felt that the fixes and data provided are quite accurate.

On pages 10 through 14 are the tracks of some of the 1951 tropical cyclones that appeared to oscillate. As can be seen by examination of these tracks, two possible types are indicated. There is quite a similarity between the track of Marge and the type of oscillatory motion described by Dr. Yeh. The track along which Marge moved was similar to a trochoid. Period of oscillation varied from 78 to 126 hours, which was much greater than that of Nora, Louise, Ruth, and Ora. The paths of these resembled the small sinusoidal waves described by Captain Horn. Generally, the period for these varied from 24 to 42 hours. Periods for all were computed to the nearest six hours.

Amplitude is rather hard to determine, for several tracks can be drawn which satisfy all fixes. For these tropical cyclones, after the best track in the opinion of the Post Analysis Board has been drawn, amplitude varied from 50 to 20 miles. The deviation was usually greater to the right of the smoothed path than to the left.

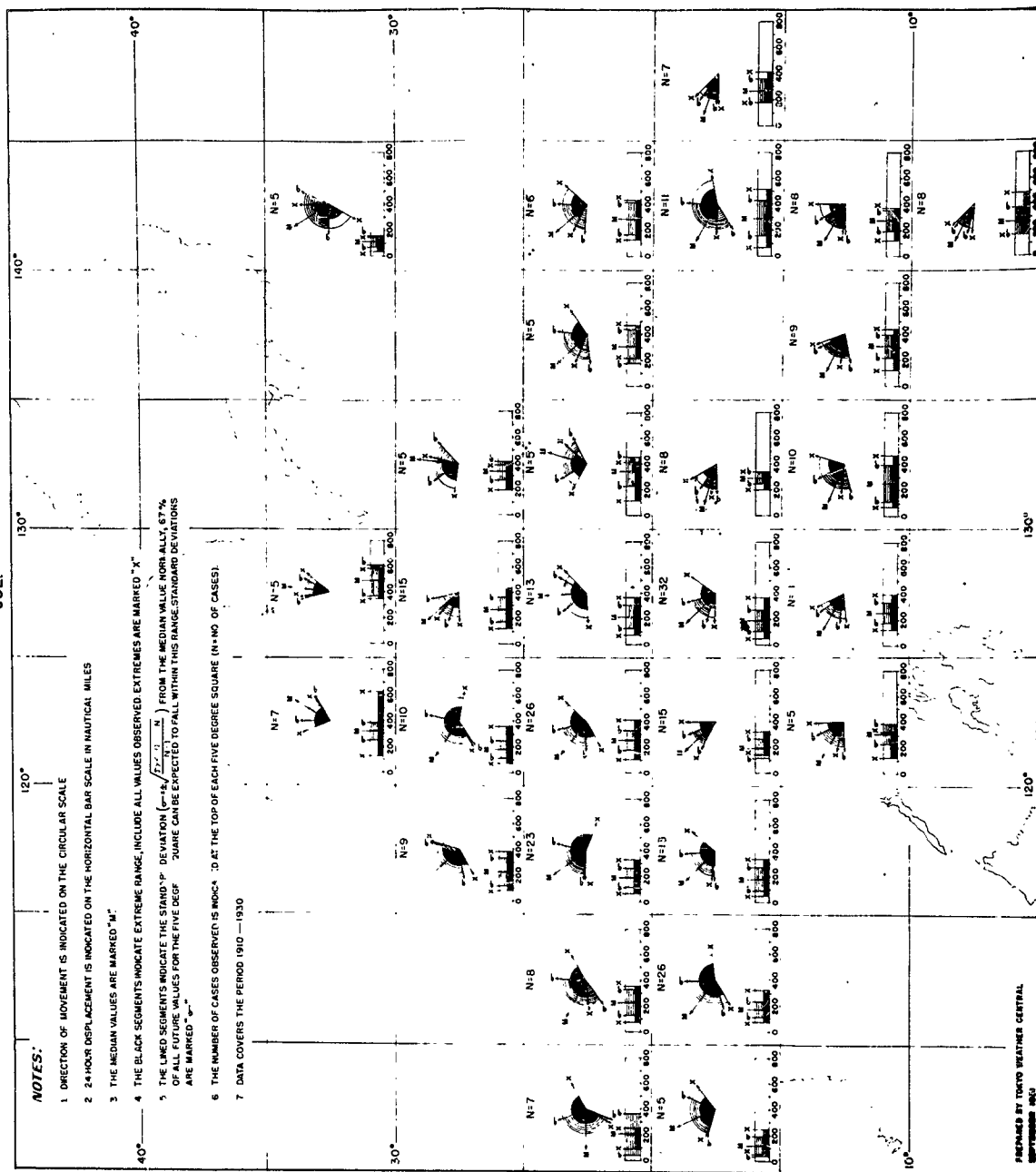
Causes of oscillations are not as yet known. Not all tropical cyclones behave in this manner. Usually oscillations appear before recurvature of slow moving tropical cyclones. It is possible that some of these oscillations are caused by passages of weak troughs in the westerlies north of the tropical cyclone. None of these troughs are strong enough to cause recurvature but appear to be of sufficient strength to cause a slight northward deflection.

The greatest value in knowing that some tropical cyclones do follow oscillatory paths is in evaluation of reconnaissance fixes. This sometimes keeps the forecaster from becoming too hasty in a forecast for recurvature if a slight north movement is indicated by one of the reconnaissance fixes.

One of the problems which is of greatest concern in forecasting tropical cyclone movement is that of recurvature. It is always a problem as to whether or not a typhoon will reach a position during the forecast period when recurvature is possible. Included on pages 17 through 22,

24 HOUR TYPHOON MOVEMENT

JULY

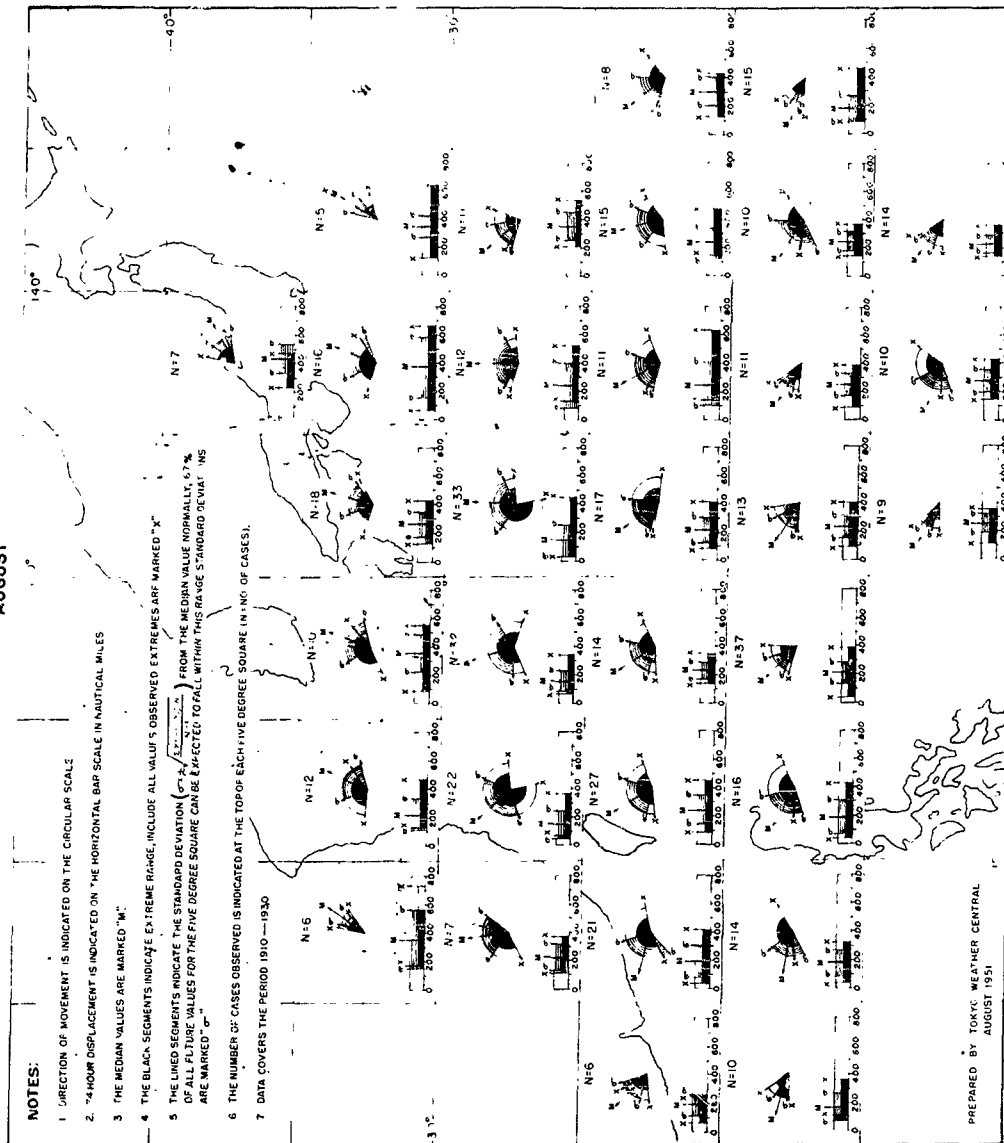


24 HOUR TYPHOON MOVEMENT

AUGUST

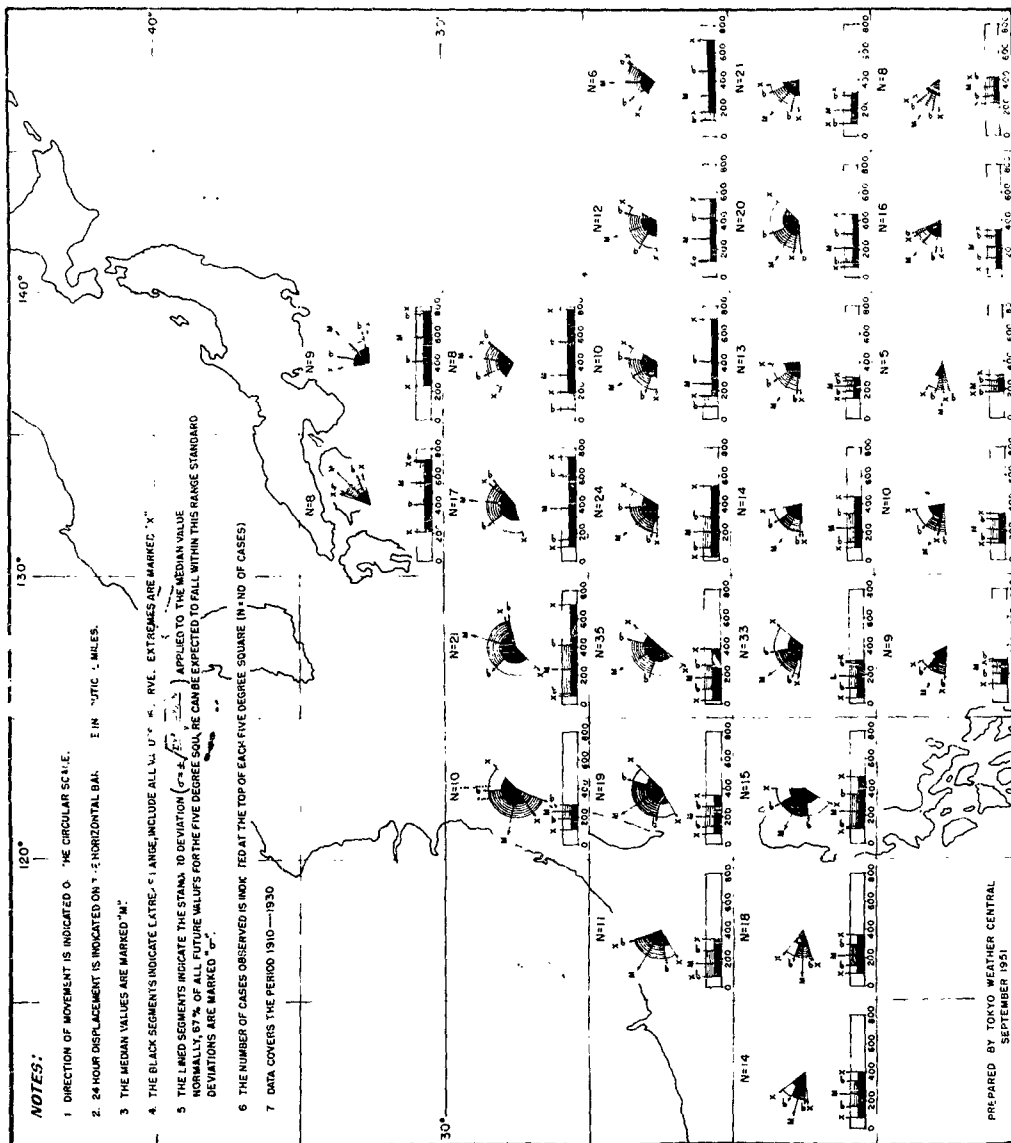
NOTES:

1. DIRECTION OF MOVEMENT IS INDICATED ON THE CIRCULAR SCALE
2. "4 HOUR DISPLACEMENT" IS INDICATED ON THE HORIZONTAL BAR SCALE IN NAUTICAL MILES
3. THE MEDIAN VALUES ARE MARKED "M"
4. THE BLACK SEGMENTS INDICATE EXTREME RANGE, INCLUDE ALL VALUES OBSERVED EXTREMES ARE MARKED "X"
5. THE LINED SEGMENTS INDICATE THE STANDARD DEVIATION (σ) FROM THE MEDIAN VALUE NORMALLY 6.7% OF ALL VALUES. VALUES FOR THE FIVE DEGREE SQUARE CAN BE EXPECTED TO FALL WITHIN THIS RANGE STANDARD DEVIATIONS ARE MARKED "σ"
6. THE NUMBER OF CASES OBSERVED IS INDICATED AT THE TOP OF EACH FIVE DEGREE SQUARE (IN NO. OF CASES).
7. DATA COVERS THE PERIOD 1910-1930



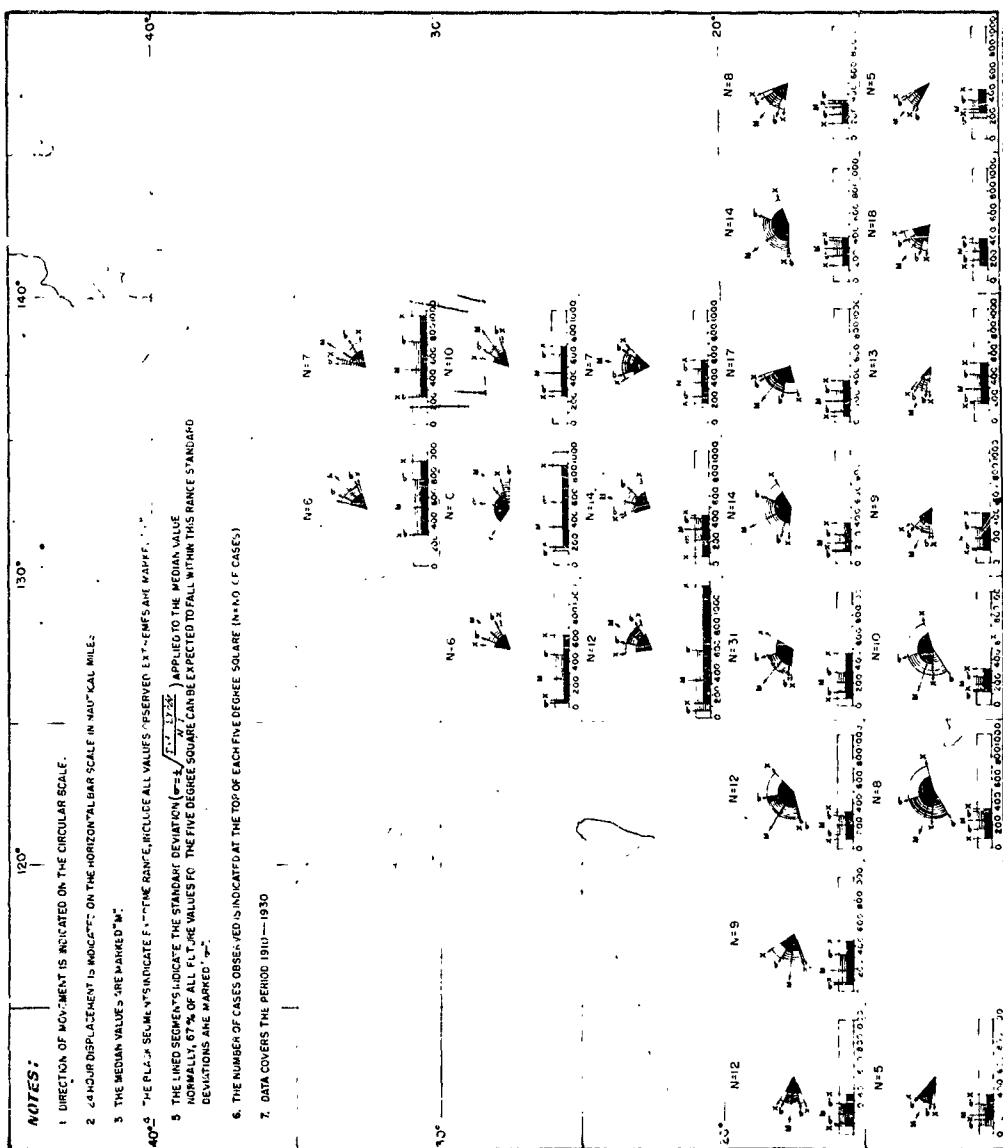
PREPARED BY TOKYO WEATHER CENTRAL
AUGUST 1951

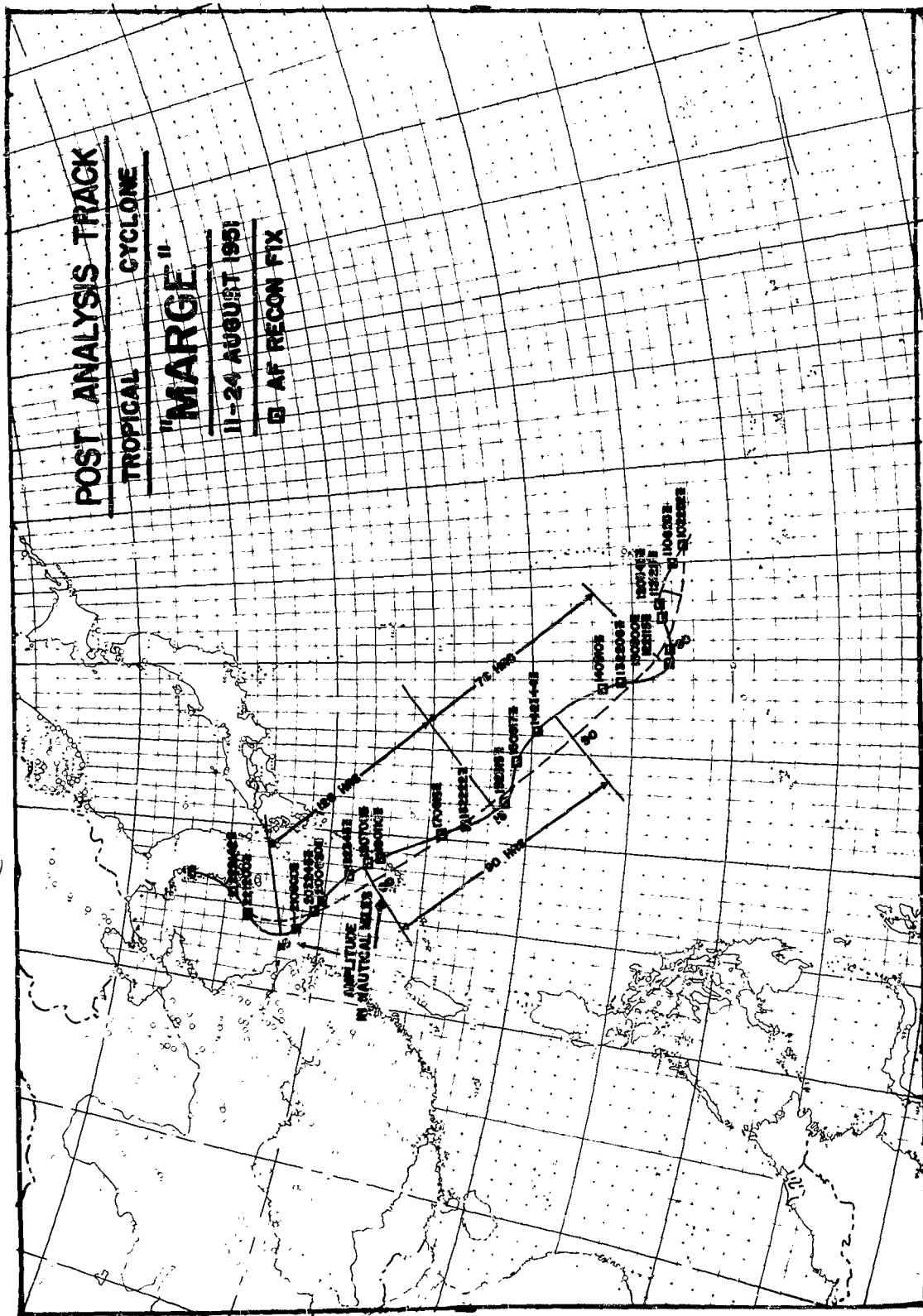
24 HOUR TYPHOON MOVEMENT SEPTEMBER



24 HOUR TYPHOON MOVEMENT

OCTOBER

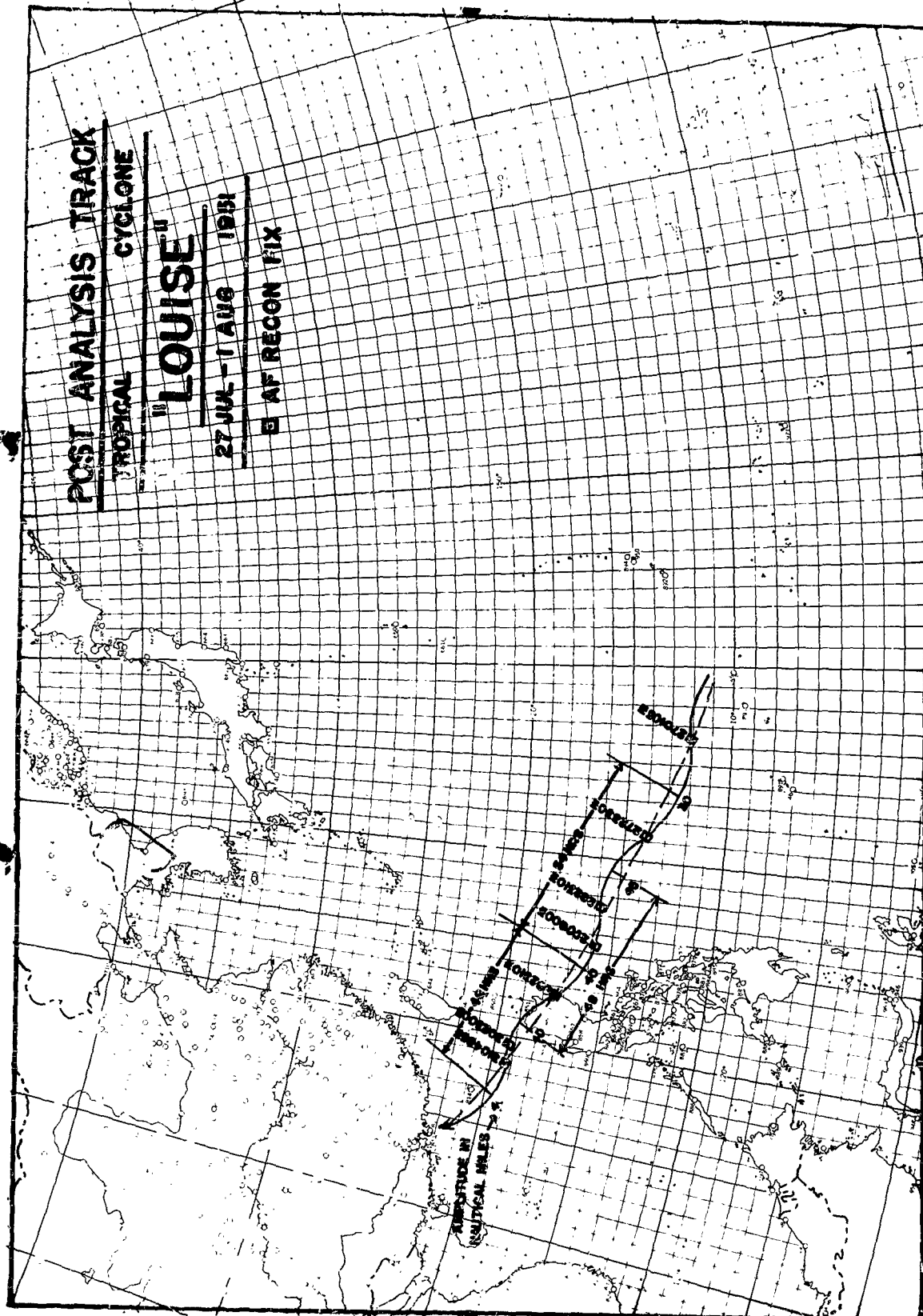




"ES NOT LOUISE"

27 JUL - 1 AUG 1951

AF RECON FIX



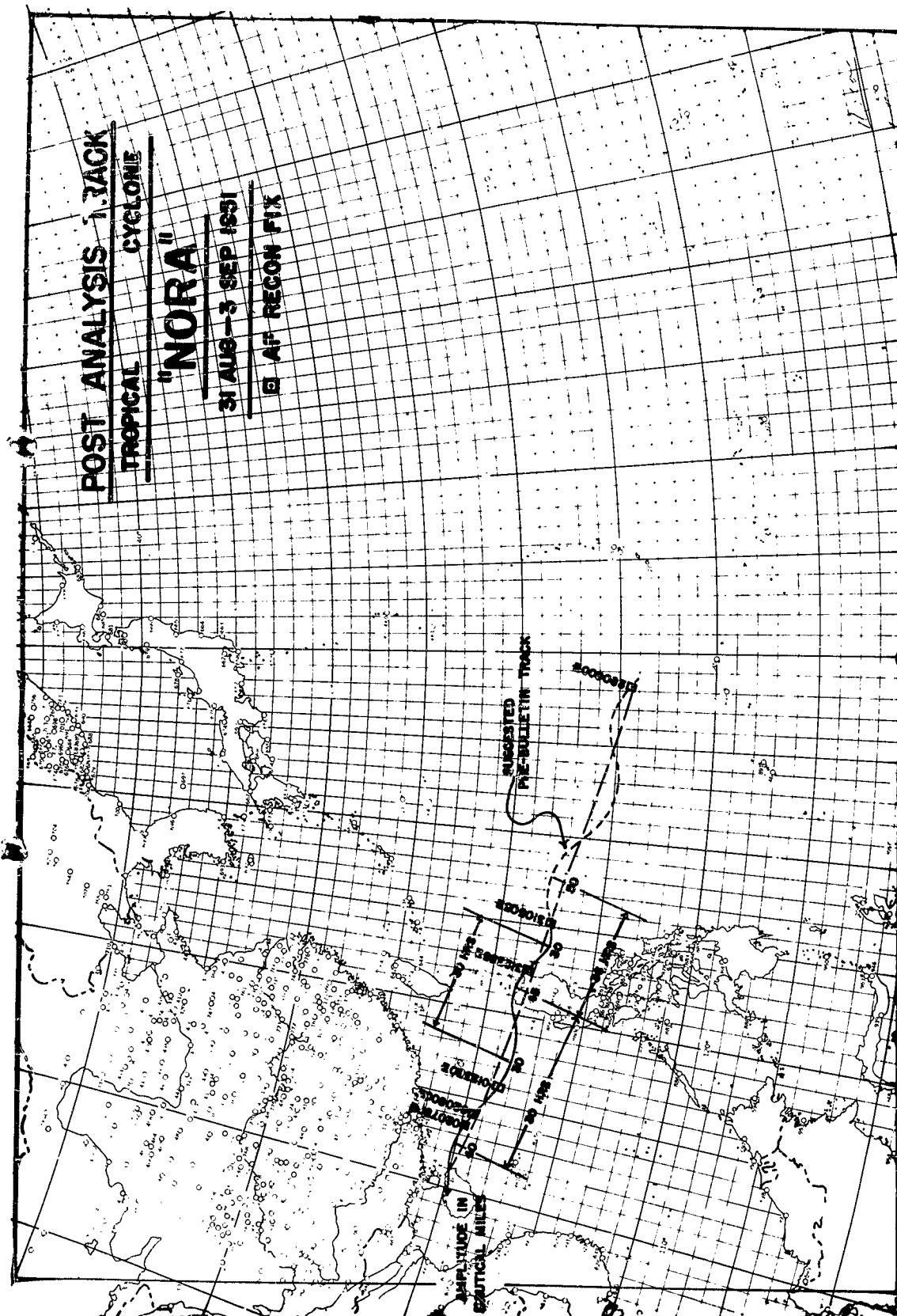
POST ANALYSIS TRACK

TROPICAL CYCLONE

"NORA"

31 AUG - 3 SEP 1951

6 AF RECON FIX



POST ANALYSIS TRACK

TROPICAL CYCLONE

"ORA"

16-21 SEPT 1961

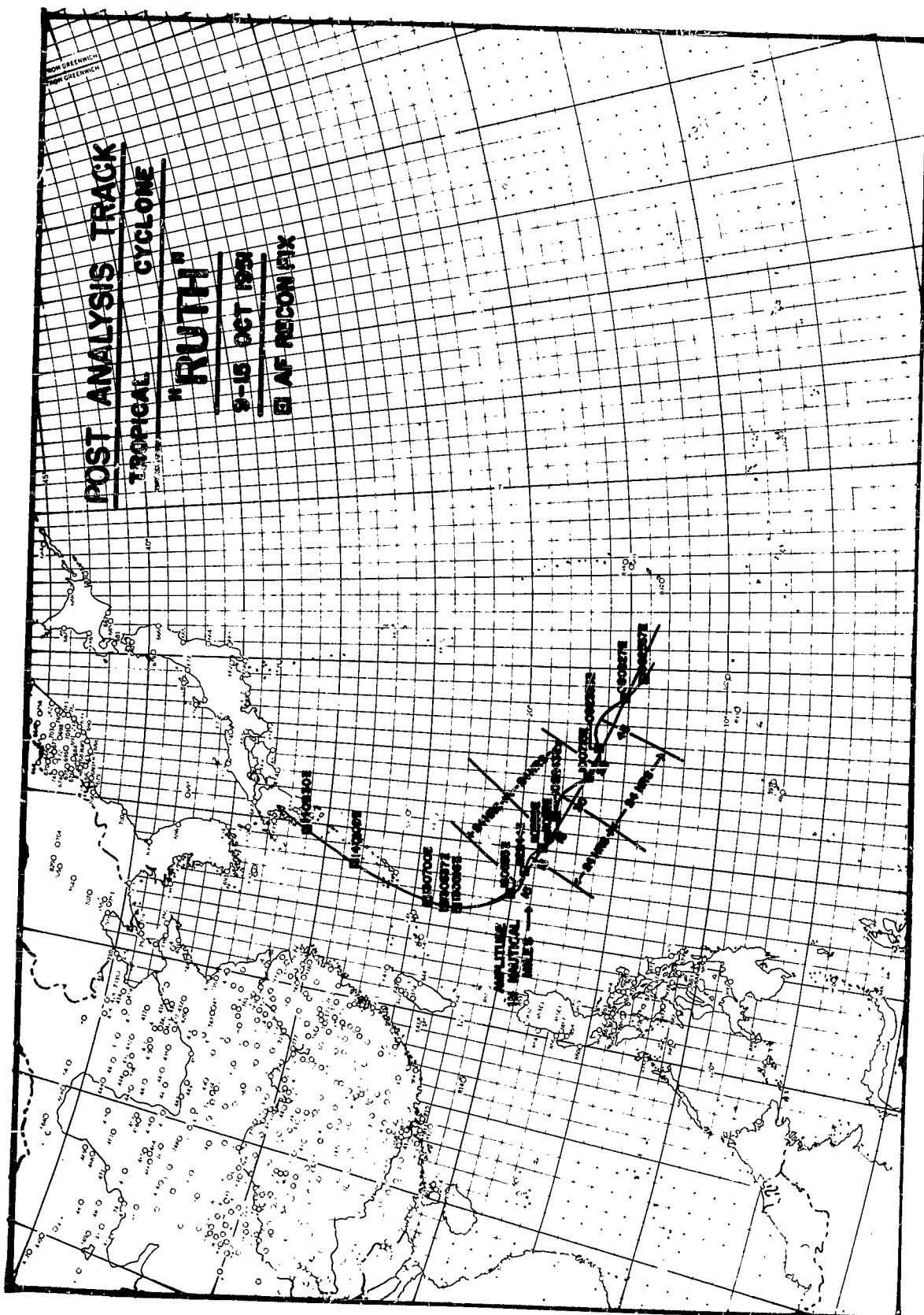
AF RECON FIX

Manila
Iloilo
Cebu
Luzon
Mindanao
Philippines
Hawaii
Scale 0 to 500 Miles

16-21 SEP 1981

AF RECON FIX

AF RECON EX



are several charts which may be of some help in determining whether or not a tropical cyclone will recurve. The most common recurvature situation arises when an extratropical trough approaches from the west. It is usually quite difficult to determine whether the trough will extend far enough south or be of sufficient intensity to cause recurvature. Normally, if the trough is moving faster than 15 knots, recurvature will not occur. There may be a deflection to the north when these troughs pass by, however. If the high cell centered to the northeast of a tropical cyclone builds, or starts moving eastward after a period of stagnation, the tropical cyclone quite often recurves. Also, when an extratropical trough approaches from the west and the high cell northeast of the tropical cyclone begins to move eastward, tropical cyclones usually recurve.

It has been stated in the past that tropical cyclones decelerate before recurving. During the 1951 season the following was noted:

	Decelerated	Accelerated After Recurvature
Iris	No	Yes
Marge	Yes	Yes
Sarah	Yes	Yes
Thelma	No (20 knots)	Yes
Babe	Yes	Yes
Ruth	Yes	Yes

6 Cases:

4 did decelerate
2 did not

Three tropical cyclones, Hope, Kate, and Joan recurved before intensifying. Positions before intensification are not accurate enough to determine the average speeds for these particular tropical cyclones. It was also observed, during the 1951 season, that Iris, Marge, Ruth, Wanda, and Amy had marked decelerations and no recurvature. The criterion of deceleration by itself is not reliable as a means of determining recurvature. All tropical cyclones during the 1951 season accelerated rapidly after recurving.

Most of the errors incurred in the forecasting of recurvature are from forecasting this to happen too soon or from forecasting too rapid a recurvature. Perhaps the best method after the decision has been made is to forecast slow recurvature with the storm moving first northwest, then north, then slowly turning northeast.

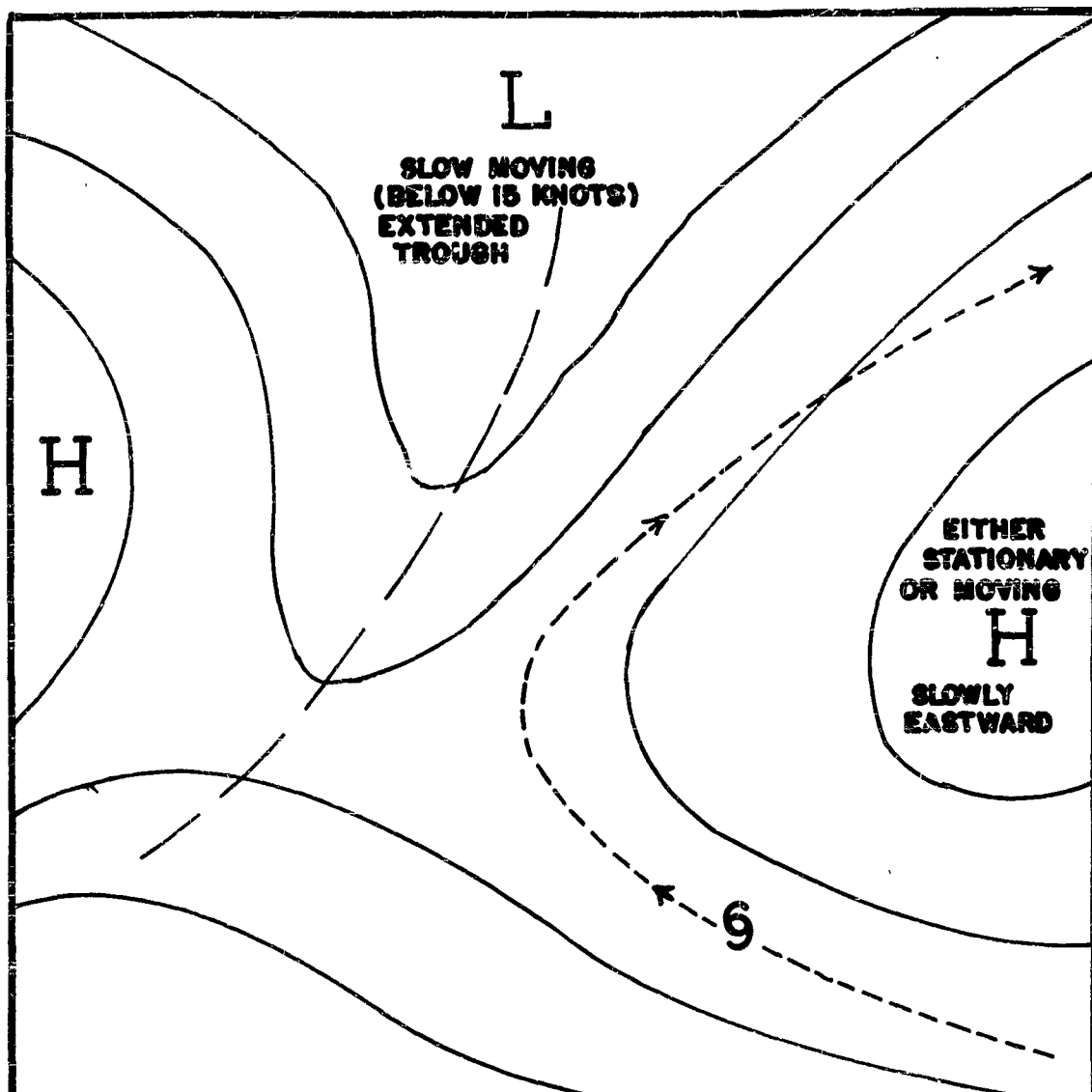
Another problem closely allied to that of recurvature is looping. During 1951, four storms looped anticyclonically. These were Joan, Iris, Hope, and Amy. Postanalysis tracks for these typhoons are included on pages 23 through 26. Joan was already recurving when detected and was moving northeast. The typhoon became stationary, then started moving southwest. Iris had recurved west of the Philippines and moved some 1500 miles northeast before looping. Hope was in the process of recurving from south of Guam and had reached a position almost due west of Guam when

looping occurred. Amy crossed the Philippines and began recurving slowly northward then became stationary and looped.

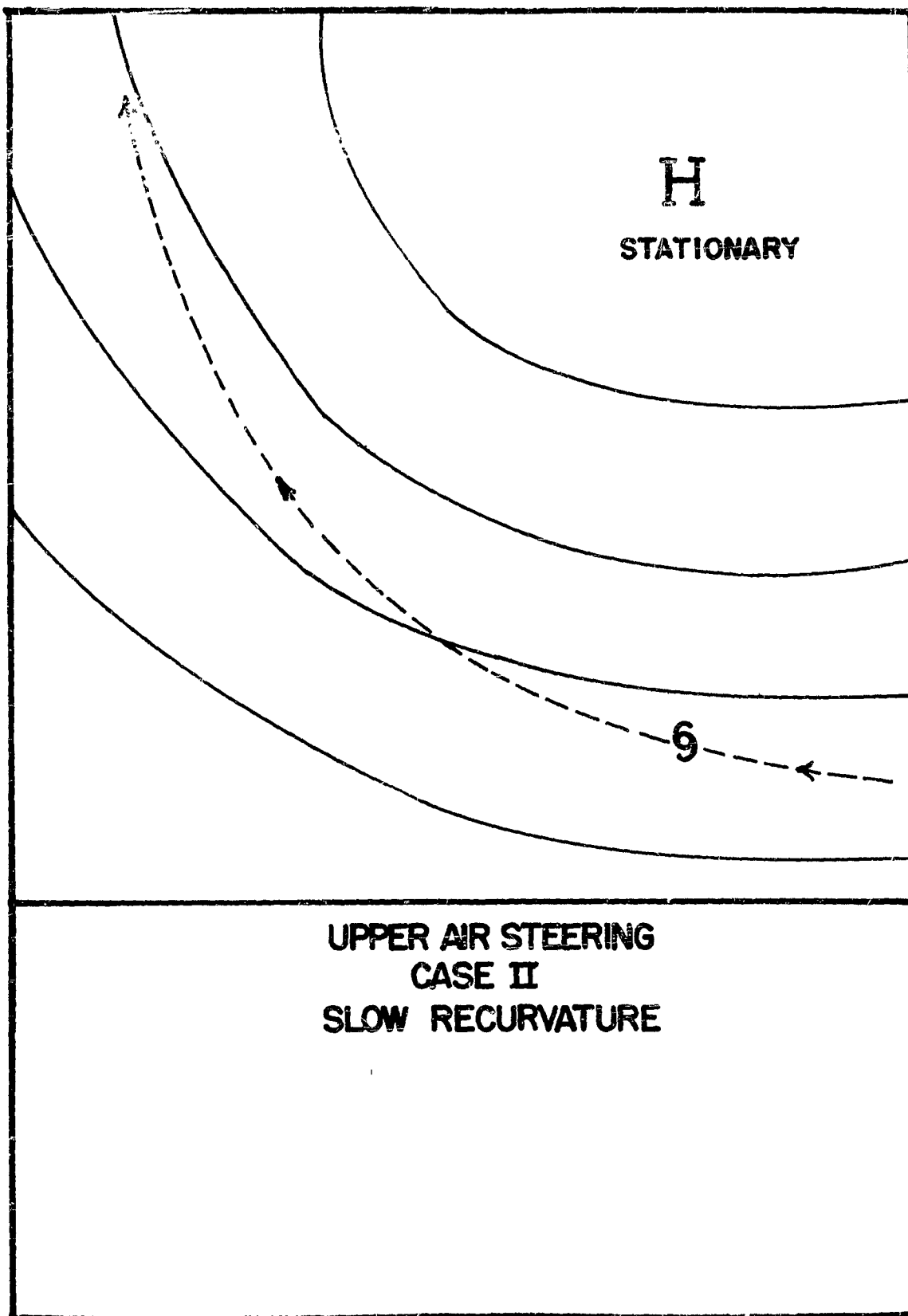
The synoptic situation is very similar to recurvature. Normally, there is a high center northeast of the typhoon with a trough approaching from the northwest. The tropical cyclone moves around the periphery of this high centered to the northeast and begins to recurve; then it reaches a position such that the high blocks further movement to the north or northeast. It then becomes nearly stationary and the trough continues moving westward, no longer influencing the tropical cyclone's movement. The tropical cyclone once again starts moving westward.

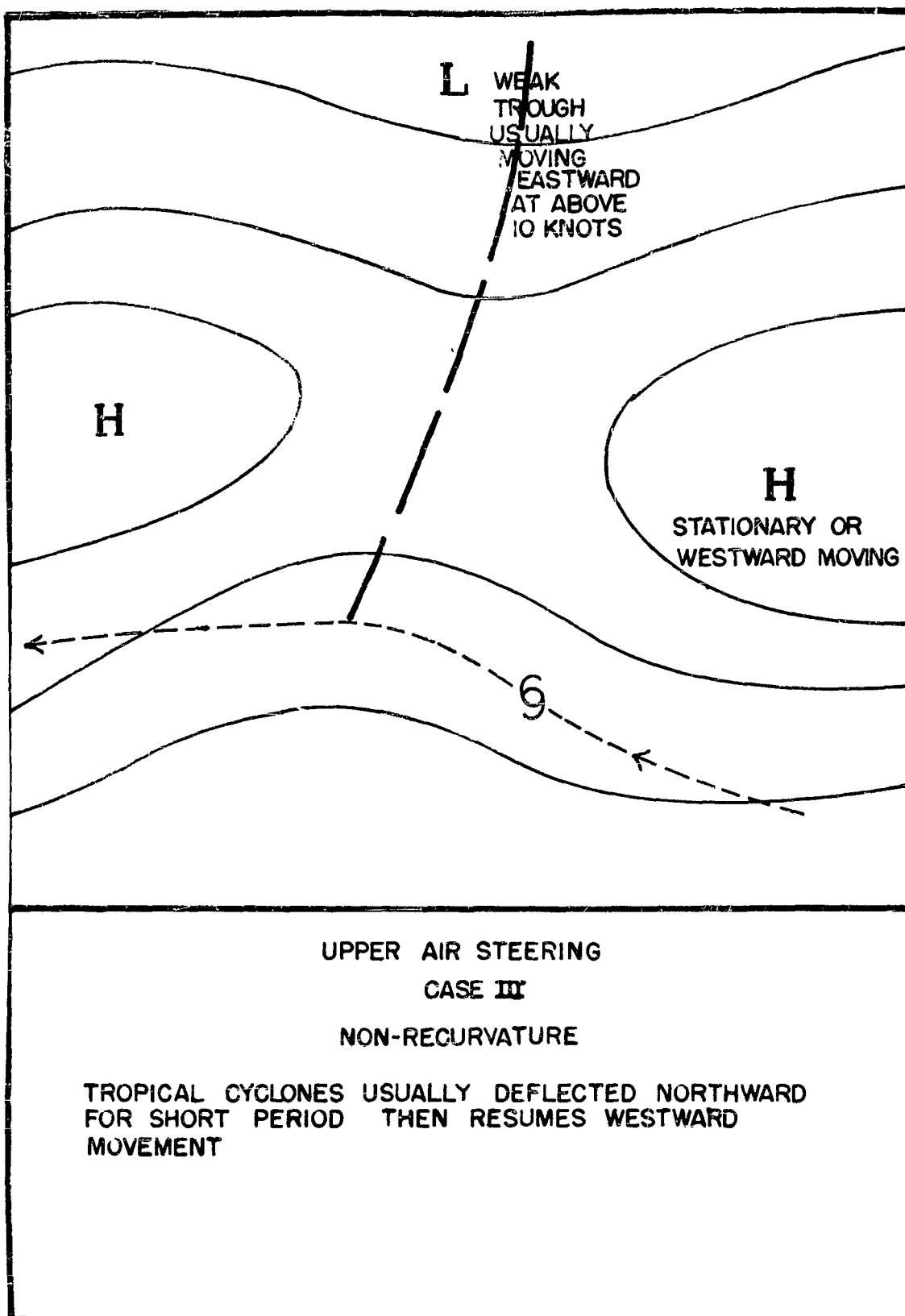
There is room for argument as to whether the typhoon actually completes an anticyclone loop or remains stationary oscillating back and forth before moving westward. For the purpose of postanalysis performed by the Typhoon Board during the past season, looping was considered to mean both of these and the tracks drawn showed slight anticyclone loops.

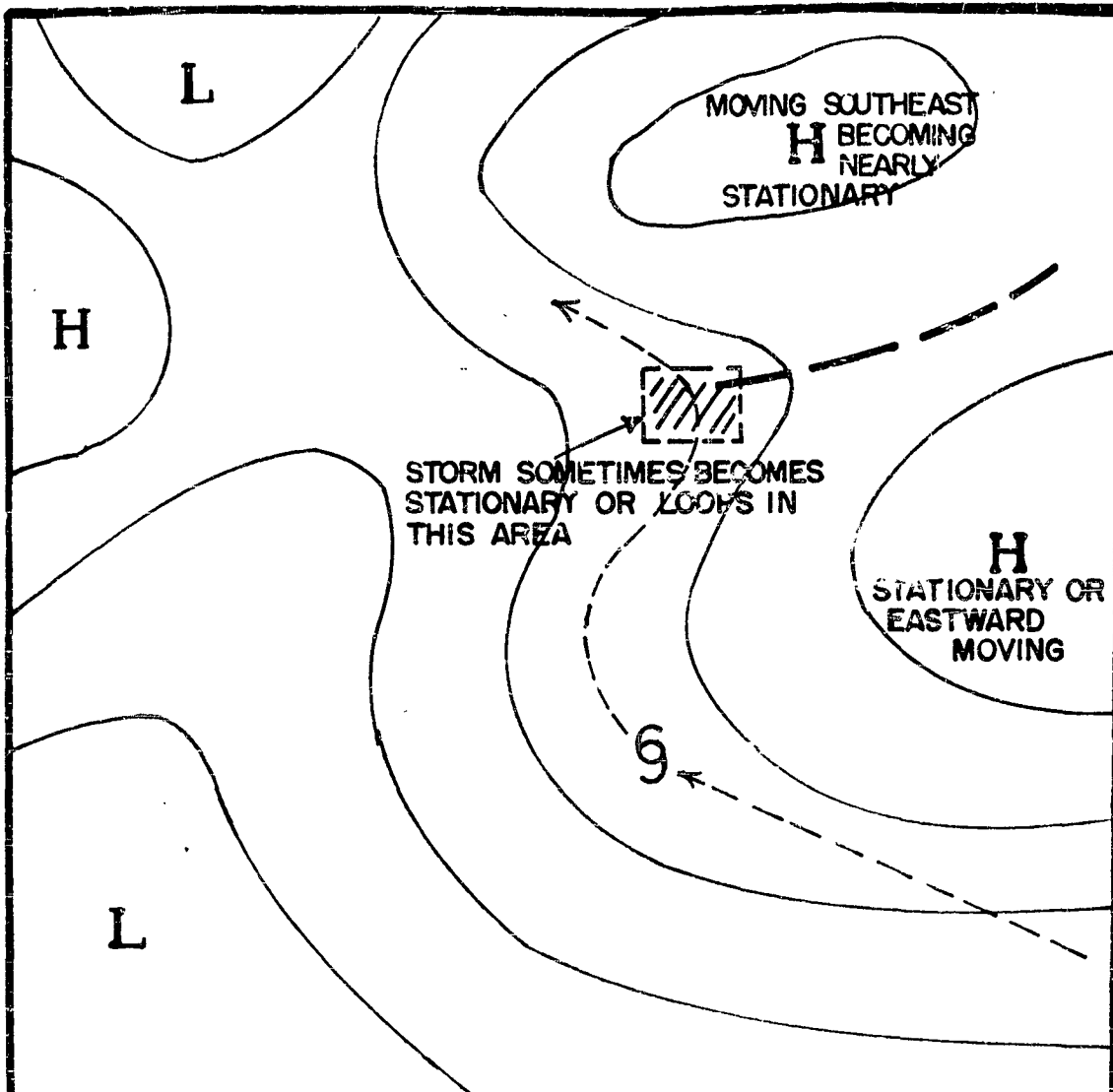
One conclusion has been drawn after postanalysis of these four tropical cyclones. This is: after completing a loop, dissipation occurs within 48 hours. This is one of the few times that tropical storms or typhoons dissipate while still over tropical ocean areas. As for the movement after looping, two moved west-southwest, and the other two moved northwest.



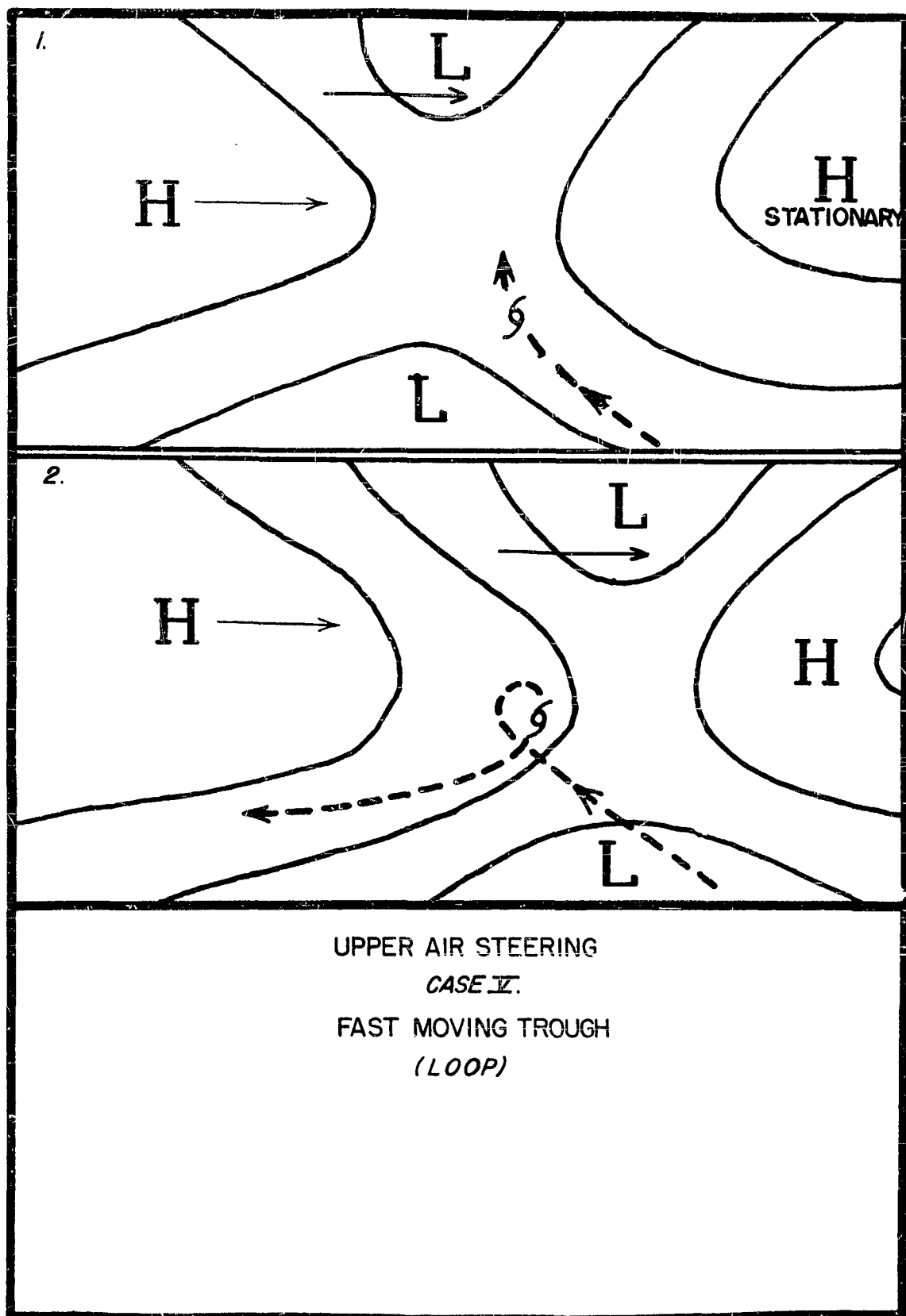
UPPER AIR STEERING
CASE I
NORMAL RECURVATURE

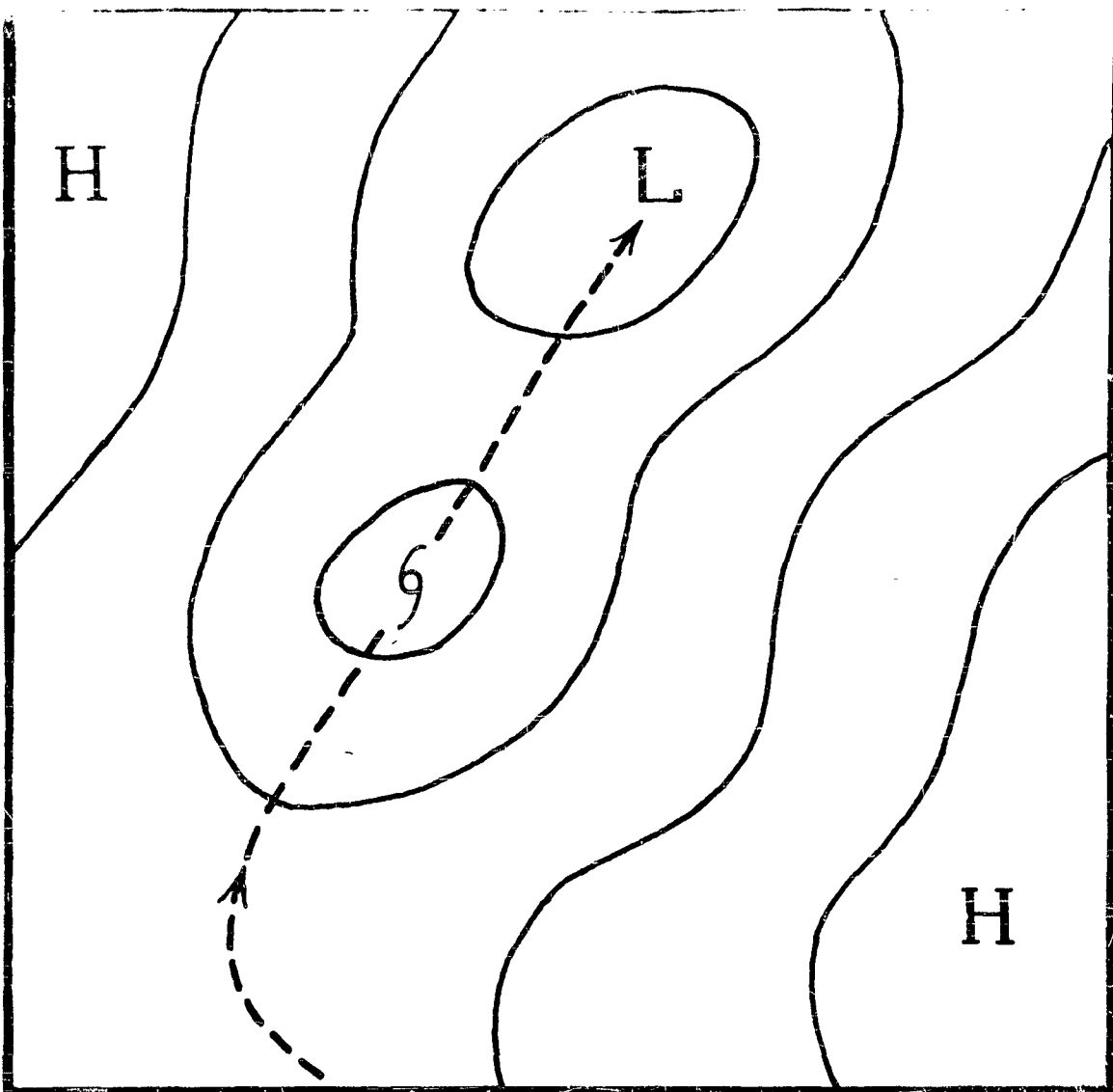






UPPER AIR STEERING
CASE IV
INVERSE RECURVATURE
OR LOOPING

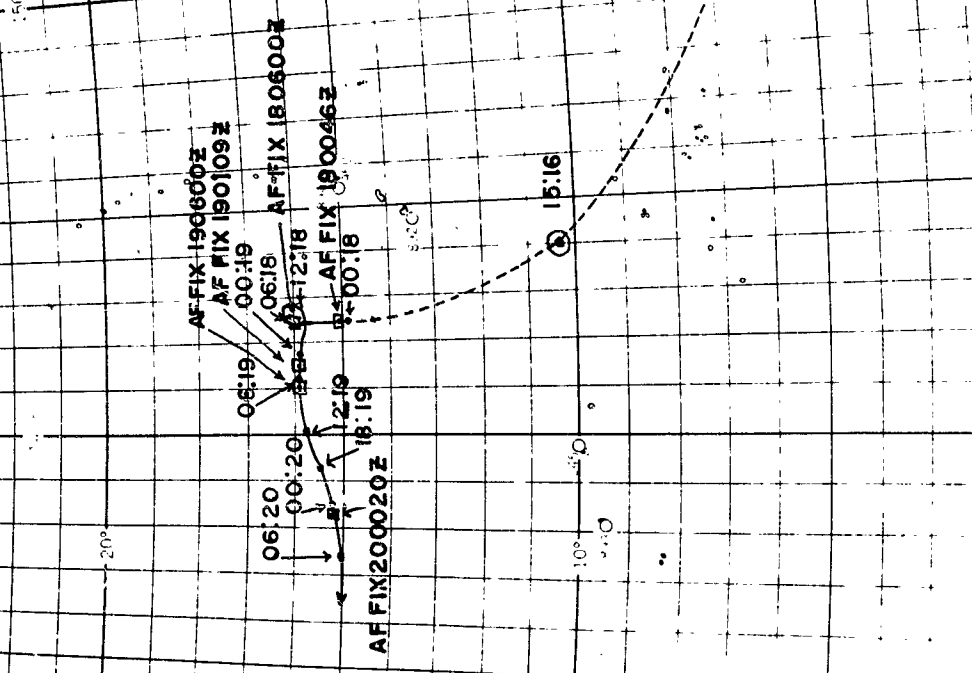




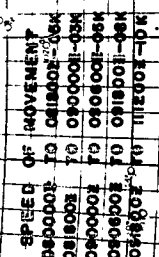
UPPER AIR STEERING
CASE VI.
STORM FOLLOWING ANOTHER STORM OR
LOW PRESSURE CELL

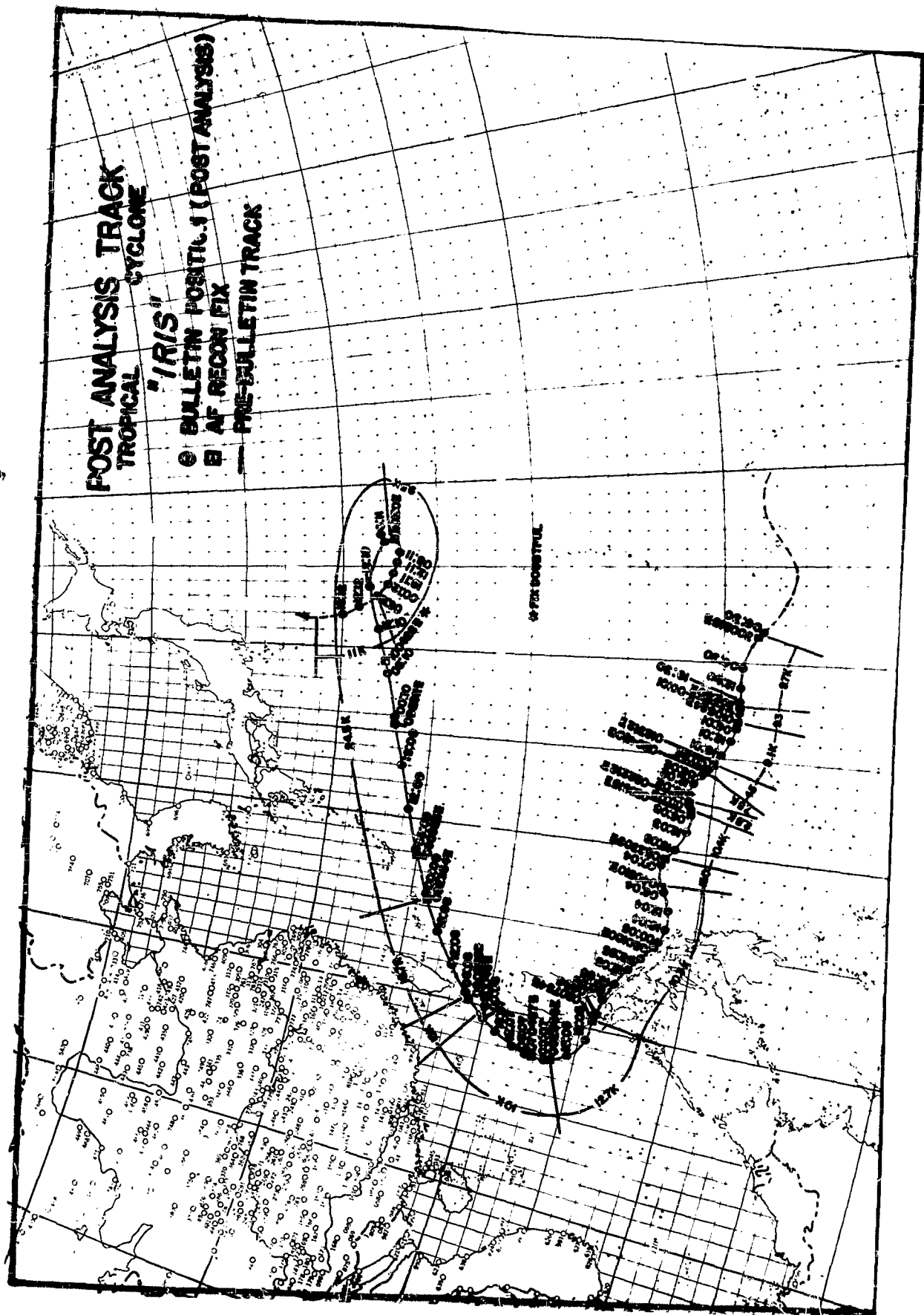
POST ANALYSIS TRACK TROPICAL CYCLONE "HOPE"

- BULLETIN POSITION
- ◻ AF RECON FIX
- POST ANALYSIS FIX
- POST ANALYSIS TRACK
- PRE-BULLETIN TRACK



PRE-BULLETIN TRACK





B. TYPHOON FORECASTING TECHNIQUES

During the 1951 "typhoon season" a new record for accuracy was attained by the Typhoon Warning Network. Many reasons have been given for this improvement such as more reconnaissance fixes, cyclones easier to forecast, etc.; however, it is believed that a portion of it resulted from the typhoon forecaster's knowledge and proper relative emphasis on the three "old standbys" of typhoon forecasting—climatology, extrapolation, and synoptic analysis.

The proper evaluation of and emphasis on the "standbys" is a skill developed by experience and will be difficult, if not impossible, to impart to the newcomer to the field in a short time. Much has been written about the evaluation of the tools as separate entities. An evaluation of this type is very difficult, due to the fact that the three are so interlocked and overlapping. Extrapolation is based upon persistence and its noted value in the past, thus climatology. Evaluation of the synoptic situation is based upon facts that have been noted about behavior of cyclones in similar situations in the past, thus climatology.

Despite the difficulties, enumerated in the paragraph above, in separately defining climatology, extrapolation, and forecasting from synoptic analysis, an attempt will be made to outline the procedure believed to produce the best results.

When only one good position is available, a forecast track should be made from climatological data, then modified with information indicated by the synoptic situation. If fixes are available, 24 or more hours apart, the initial track should be made by obtaining the direction of movement from climatology and the speed from extrapolation or persistence. This forecast then should be modified cautiously by information obtained from synoptic analysis. It is believed that the forecaster should be more cautious about modifying, with synoptic analysis, in the lower latitudes than in the more northern areas. Further, the forecaster can place more emphasis on synoptic analysis when recurvature is occurring. Synoptic analysis could better be used to forecast recurvature, acceleration and deceleration, if sufficient data were available to determine the position, movement, and extent into the tropics, of long waves. A Northern Hemisphere analysis at 200 and 700 millibars, received by facsimile, would be invaluable in using the behavior of the long wave train as an aid to tropical cyclone forecasting. In addition, the 200 millibar level could be used to determine whether convergence or divergence exists above the cyclones. A study of this upper-air convergence and divergence has been an aid in forecasting intensification or decay even though very few data were available at the 200 millibar level.

The equi-pressure bisector method was used to fix centers of cyclones in the area where a number of reports were available. The area of sufficient data was, of course, north of the flat pressure field of the tropics, therefore, no evaluation of this method could be made for the lower latitudes.

The 24-hour pressure change profile and wind profile were used quite extensively by all units of the Typhoon Warning Network during the 1951 season. The primary advantage of this method was the fact that it can be used to advantage when only one report is available from a station under the influence of the cyclone.

The use of the "steering level" method has been rather unsuccessful during the past season. Occasionally, during recurvature, it could be noted that the path of a cyclone was following the flow at a certain level and a good forecast direction obtained.

The Andersen Center and the Clark Sub-center had considerable success in forecasting oscillatory movement of tropical cyclones as outlined by Horn. The forecaster must wait until an oscillatory track is established by three or four fixes before he can determine the position of a cyclone in relation to the oscillatory track. The accuracy added to a forecast by forecasting oscillations instead of a mean path is admittedly small, but it is believed that every effort should be made to increase accuracy. Many tropical cyclone forecasters are not convinced that many cyclones follow oscillatory tracks, but the reconnaissance fixes during the 1951 season present a strong argument for the existence of such tracks. It may be noted here that practically all forecasters in this area have gained a considerable respect for the accuracy of reconnaissance fixes during the 1950-1951 seasons due to the fact that fixes which at first seem to represent a very unusual situation are usually quite credible when viewed in the light of an oscillatory track. Extrapolation has been used more accurately because the oscillatory tracks point out the necessity of the two fixes used being at least one wavelength apart for best results.

In review, the methods and techniques most usable to the Typhoon Warning Network are extrapolation, climatology, and synoptic analysis, with sub-divisions of equi-pressure bisector, 24-hour pressure profiles, wind profiles, upper-air convergence and divergence, long wave effects, upper latitude system effects, and forecasting movement along an oscillatory track. These are the main ingredients of tropical cyclone forecasting during the 1951 season, and when properly mixed with a leavening of experience they will give the best possible forecast until such time as research reveals more valuable methods, techniques and aids.

C. ERROR ANALYSIS

In an effort to evaluate the services provided by the Typhoon Warning Network, errors for bulletin location, 12-hour forecasts, and 24-hour forecasts have been computed for all bulletins and forecasts issued during the 1951 Typhoon Season. The purpose of such an evaluation is twofold. First, it is to note points of weakness and to suggest possibilities for improvement. Second, it is to provide the Network with a guide to its capabilities in providing advance warning to using agencies. Normally, users of the Typhoon Warning Service are not as interested in the theory of forecasting typhoon movement and intensity as they are in the receipt of accurate forecasts far enough in advance of the tropical cyclone's arrival to take necessary protective measures. For this latter reason, therefore, the method of distance evaluation was used.

In this method of distance evaluation a postanalysis track, based upon all available data, is drawn. Because of the few reporting stations in the area through which most typhoons move, synoptic analysis is not of much help in accurate locating of position. Most accurate and, also, most used are reconnaissance fixes. These are supplemented by land radar fixes when available. In drawing a curve to satisfy a set of points, it is quite often possible to draw several quite similar paths. However, in drawing the postanalysis track a sincere effort is made to draw that track which best satisfies all fixes and data. Postanalysis positions corresponding to USAF bulletin times are included on this track. To compute the error the distance in nautical miles is measured between the position indicated on the AF bulletin and the position for the corresponding time indicated on the postanalysis track.

Fast Position
fr AF Bulletin

Error

06:12

Postanalysis
Track

Various error charts and graphs are included in this report. On page 30 is included a chart showing average errors incurred by the network as a whole for each individual tropical cyclone. These average errors have been corrected and differ slightly from those which appeared in the individual tropical cyclone reports. For the entire 1951 season, these averages in nautical miles are as follows:

ERRORS INDIVIDUAL CYCLONES FOR NETWORK

	Bulletin Error	12-Hour Forecast Error	24-Hour Forecast Error
Georgia	35	80	125
Hope	45	150	315

ERRORS INDIVIDUAL CYCLES FOR NETWORK (cont'd)

	Bulletin Error	12-Hour Forecast Error	24-Hour Forecast Error
Iris	50	100	150
Joan	45	120	205
Kate	20	85	150
Louise	20	45	70
Marge	20	70	130
Nora	15	65	120
Ora	25	60	135
Pat	40	140	230
Ruth	20	70	140
Sarah	60	145	275
Thelma	25	85	185
Vera	5	85	275
Wanda	30	75	125
Amy	25	70	130
Babs	30	115	210
Average	30	85	150

All figures in nautical miles.

These averages compare with those of the 1949 and 1950 season as follows:

	Bulletin Location	12-Hour Forecast	24-Hour Forecast
1949	50	105	190
1950	50	115	190
1951	30	85	150

An improvement is noted in both bulletin location and forecasting averages. There are several probable reasons for this. One of the most apparent is in the excellent reconnaissance support rendered. There was a marked increase not only in fixes provided but also in reconnaissance fixes obtained per AF bulletin issued. This can be compared as below:

	Number of Fixes	Number of Bulletins	Ratio Fixes/Buls.
1951	168	400	1/2.4
1950	69	294*	1/4.3
1949	50	302	1/6

*This does not include 49 bulletins issued east of 180 degrees longitude, as no provisions were made for reconnaissance east of 180 degrees at that time.

Reconnaissance fixes alone are not the answer to the forecast problem. However, by judicious use of these, forecasting can be improved.

A breakdown of average errors incurred by each network unit for each individual tropical cyclone is included on pages 34 through 38. The overall averages for the entire season are as follows:

	No. of Bul.	Bul. Loc.	12-Hr Fcst	24-Hour Fcst
Andersen	138	30	85	145
Clark	154	25	70	125
Tokyo	108	35	110	195

These compare with the 1950 and 1949 averages as follows:

	No. Bul.	Bul. Loc.	12-Hr Fcst	24-Hr Fcst
Andersen 1951	138	30	85	145
1950	69	35	90	160
1949	100	70	140	225
Clark 1951	154	25	70	125
1950	41	45	105	180
1949	93	50	90	170
Tokyo 1951	108	35	110	195
1950	144	60	125	210
1949	83	30	70	135

(Bulletins issued by Kadena are not included in these comparisons as this station was dropped from the Network in 1951.)

It should be mentioned that comparison of averages between the various network units is not necessarily a comparison of forecasting ability. Each network unit has its own forecasting problems. In the Guam area of forecast responsibility, where there are normally few data available, forecasting is done for the early stages of a tropical cyclone's life cycle, when the storm is ill-defined and little accurate history available, even though the original disturbance might have been tracked from as far east as Kambien. Although the Easterly Wave Program is of great value in following the progress of these disturbances, usually the position is no more accurate than one degree of longitude. Centers of vortices are difficult to place within two degrees of latitude by

analysis of time-cross-sections for individual stations. Normally, it is only after reconnaissance enters the picture that accurate location is possible. At any time after detection, recurvature is possible.

In the Clark area of forecast responsibility, problems are quite similar to those outlined above, except that usually there is more history of movement and intensity. A lack of data makes the use of reconnaissance necessary for location at present positions. Again, recurvature is possible at any time.

Forecasting problems change somewhat in the Tokyo area of responsibility. There is usually more data available for locating present locations, and the problem of recurvature is not so great, for, normally, the tropical cyclone has already recurved or is in an advanced stage of recurvature. However, rapid acceleration to speeds in excess of 25 knots are not uncommon. This does present a problem, for the track may be well forecast, but an error in speed of only five knots will result in an error of 120 nautical miles, assuming the bulletin position to be without error.

These individual network unit average are, therefore, included, not necessarily for comparison between each other, but, rather, for comparison with results in the same areas for previous years. In general, the results indicate that bulletin locations have improved during the three year period. This is particularly true in the Guam and Clark areas of forecast responsibility. There has been a trend for improvement of both the 12- and 24-hour forecasts, also.

Quite often averages are misleading. For this reason, distribution graphs of the errors made by the network, and, also, by individual network units have been prepared. These are included on pages 43 through 48. Inspection of these graphs show that the network was able to issue bulletins 80 per cent of which had 30 miles or less error for present position. Also, 75 per cent of the 12-hour forecasts were accurate within 85 miles or less. Approximately 70 per cent of all 24-hour forecasts made were equal to or less than the 150 mile average.

A comparison between the distribution of these errors and those for 1950 is included on the graphs, pages 43 through 45. These show an improvement for the network as a whole, over the 1950 season, as can be seen by the following:

	1950	1951
% Bulletin location below 30 nautical miles	40	80
% 12-hour forecasts below 85 nautical miles	50	75
% 24-hour forecasts below 150 nautical miles	50	70

In order to evaluate linear extrapolation and climatology as forecasting tools, a comparison between 24-hour forecasts made by these and the actual 24-hour forecast was made. Only linear extrapolation was used in making this comparison because of the inherent difficulties in any system of verifying modified extrapolation after the typhoon has occurred. A sincere effort has been made to evaluate each of these in the fairest manner, and it is quite possible that errors for both extrapolation and climatology are smaller than would have occurred had the forecast been made at the same time and under the same conditions as the actual forecast. It is suggested that 24-hour forecast position using these tools be included on the forecaster work sheets. Pages 49 through 50 include distribution graphs comparing the three types of forecasts.

ERROR CHART
1951 TROPICAL CYCLONES
Andersen Weather Central

	Bulletin Location	12-Hour Forecast	24-Hour Forecast	No. of Bulletins
Georgia	35	80	125	17
Hope	45	150	315	10
Iris	25	50	85	16
Joan	45	115	205	13
Louise	15	50	65	5
Marge	20	60	115	20
Nora	0	50	85	1
Ora	15	60	80	2
Ruth	25	60	95	12
Thelma	40	120	245	9
Wanda	105	175	225	3
Amy	30	85	140	16
Babs	25	105	175	14
Average	30	85	145	Total 138

All errors in Nautical Miles

ERROR CHART
1951 TROPICAL CYCLONES
Clark Sub-center

	Bulletin Location	12-Hour Forecast	24-Hour Forecast	No. of Bulletins
Iris	25	60	110	21
Kate	30	100	100	2
Louise	20	45	70	18
Nora	20	70	125	12
Ora	25	60	140	20
Pat	45	140	230	7
Wanda	20	65	110	27
Amy	25	65	125	42
Babs	50	140	270	5
Average	25	70	125	Total 154

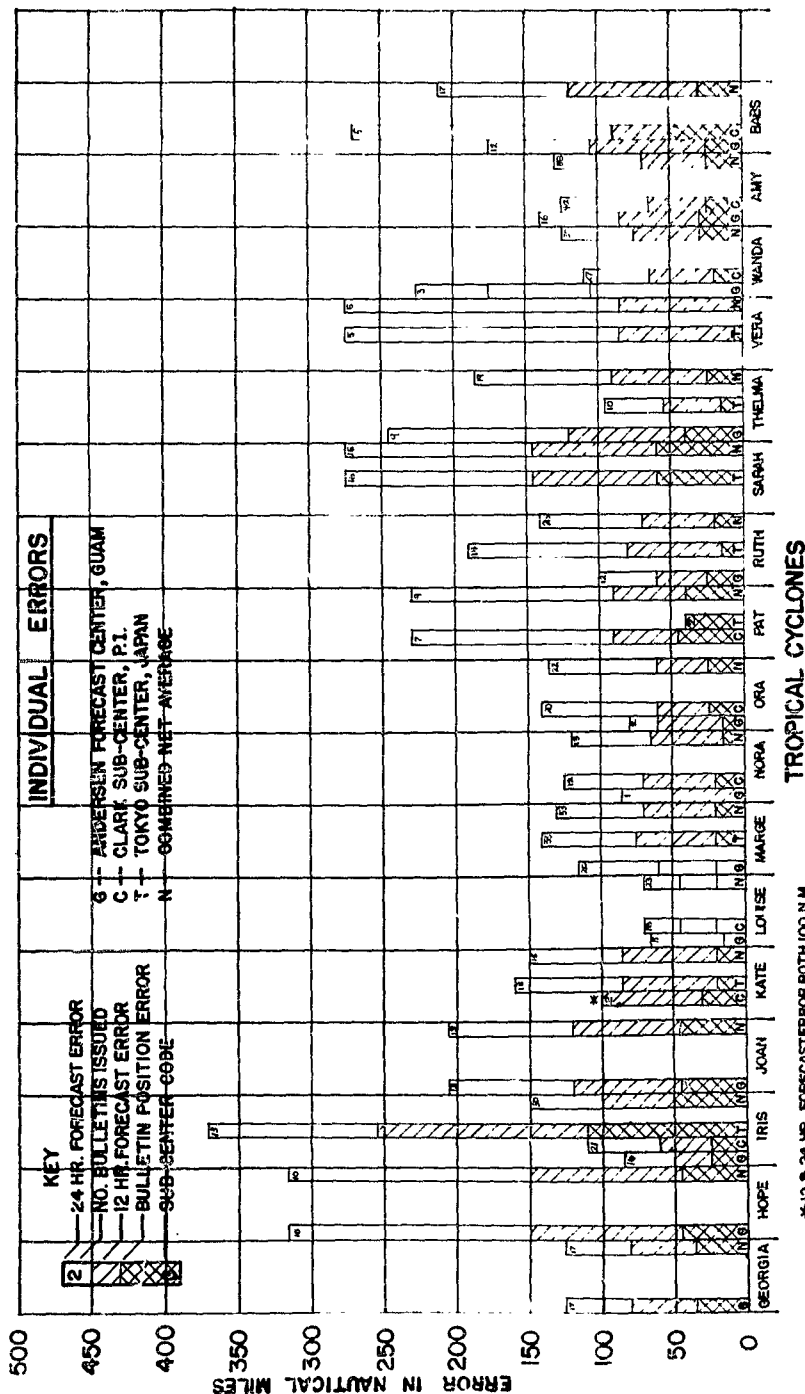
All errors in Nautical Miles

ERROR CHART
1951 TROPICAL CYCLONES
Tokyo Sub-center

	Bulletin Location	12-Hour Forecast	24-Hour Forecast	No. of Bulletins
Iris	120	255	370	13
Kate	15	85	160	13
Marge	20	75	140	33
Pat	40	-	-	2
Ruth	15	80	190	14
Sam	80	145	275	16
Thelma	15	55	95	10
Vera	5	85	275	6
Wendy	-	-	-	1
Average	35	110	195	Total 108

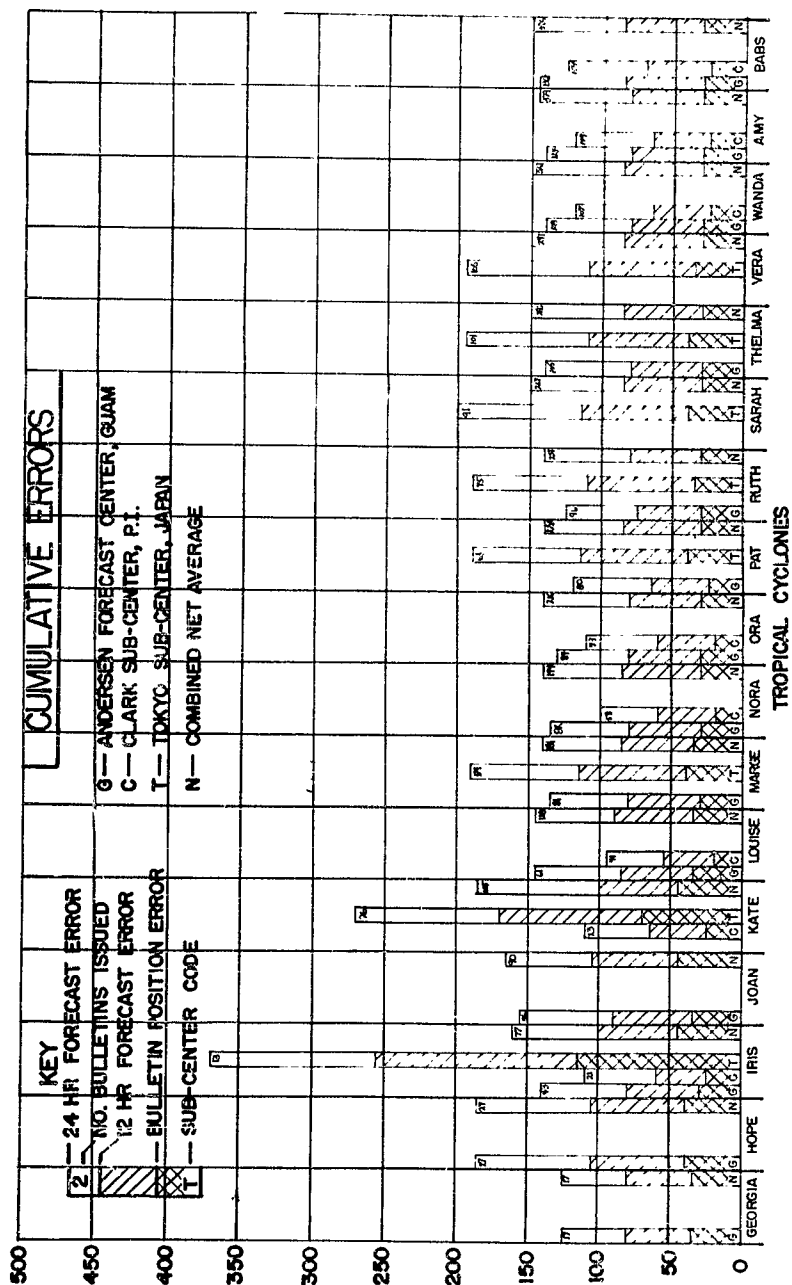
All errors in Nautical Miles

ERROR GRAPH 1951 TROPICAL CYCLONES



* 12 & 24 HR. FORECAST ERROR BOTH 100 N.M.

ERROR GRAPH **1951 TROPICAL CYCLONES**



The comparison of these three, extrapolation, climatology, and the actual forecast indicate slightly better results for the actual forecast. However, it must be remembered that all three forecasts are interrelated, that is, usually an extrapolated path is drawn, then is modified by climatology and synoptic analysis. The results then are pretty much as might be expected.

All in all, error analysis for the 1951 season shows an improvement in forecasting in each area over the 1950 season. It should be mentioned that this type of analysis is not the only means of evaluating the Typhoon Warning Service. It has been suggested that the errors be correlated to speed of movement. Lack of time prevents this being done for this particular Annual Report. However, it is suggested that in the future an attempt be made to correlate errors with change in direction and change in speed. It is during periods of change that the largest errors do occur. There are several pitfalls in this type of correlation, one of the most obvious of which is when a typhoon becomes nearly stationary. This presents one of the most difficult of forecasting problems and, if correlated to speed alone, it would appear to be a simple one.

In addition to the improvement in forecasting, operation of the Network as a whole showed improvement. No major SOP violations were noted. Typhoon forecasters were more familiar with procedures, which improved the services provided.

ERROR GRAPH 1950 TROPICAL CYCLONES

INDIVIDUAL ERRORS

KEY

- 24 HOUR FORECAST ERROR
- NO. BULLETINS ISSUED
- 12 HOUR FORECAST ERROR
- BULLETIN POSITION ERROR
- SUB-CENTER CODE

- ANDERSEN WEA. CENTRAL, GUAM
- CLARK SUB-CENTER, P.I.
- KADENA SUB-CENTER, OKINAWA
- TOKYO SUB-CENTER, JAPAN
- COMBINED NET AVERAGE

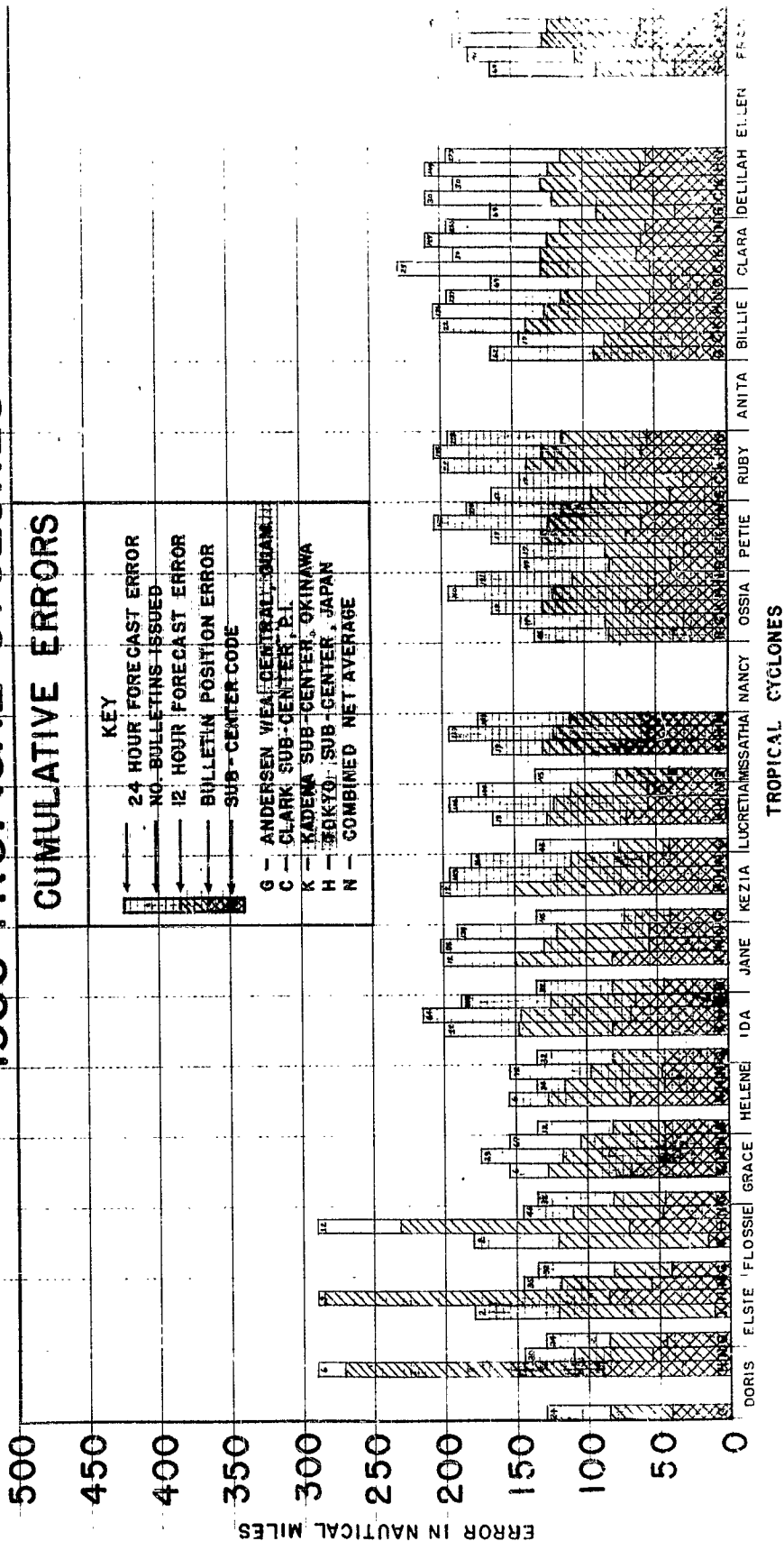
500
450
400
350
300
250
200
150
100
50
0

ERROR IN NAUTICAL MILES

DORIS | ELSIE | FLOSSIE | GRACE | HELENE | IDA | JANE | KEZIA | LUCRETIA | MISSATHA | NANCY | OSSIA | PETE | RUBY | ANITA | BILLIE | CLARA | DELILAH | ELLEN | FRANK

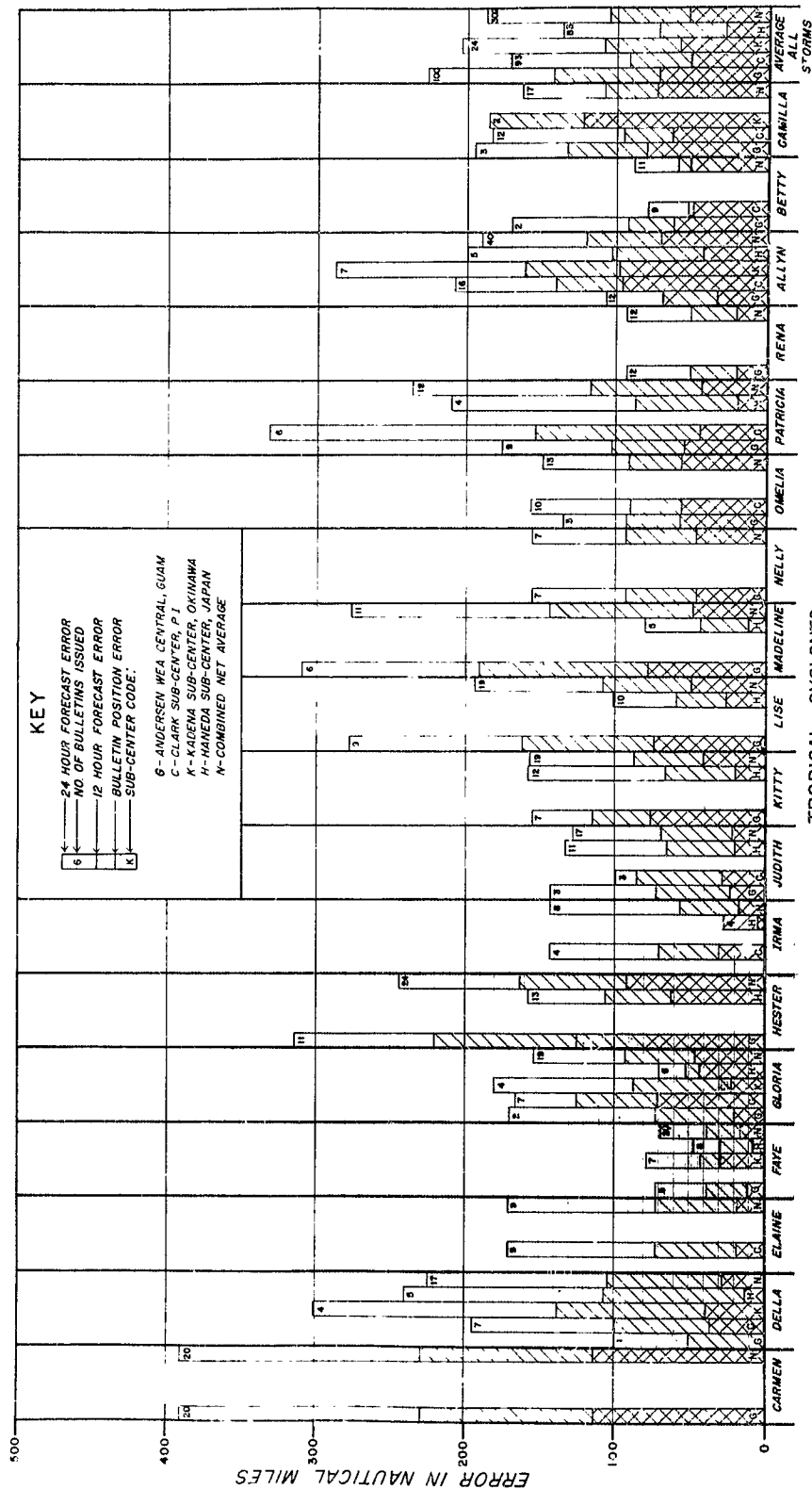
TROPICAL CYCLONES

ERROR GRAPH 1950 TROPICAL CYCLONES

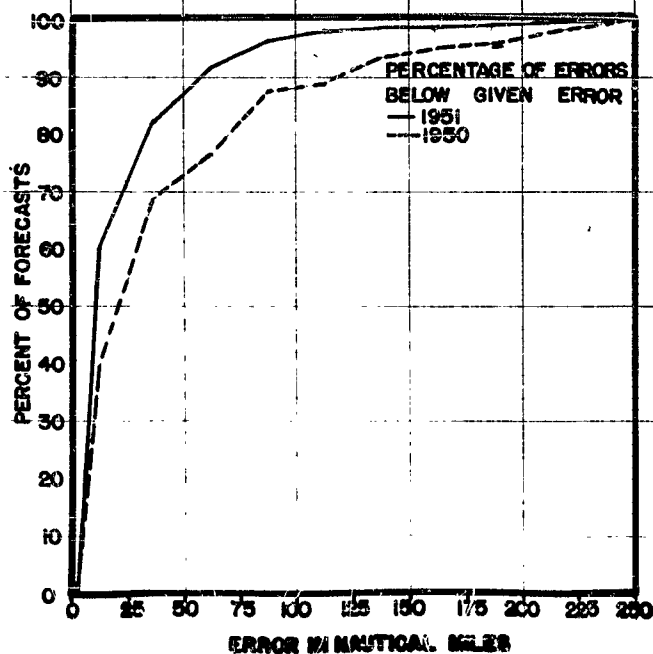
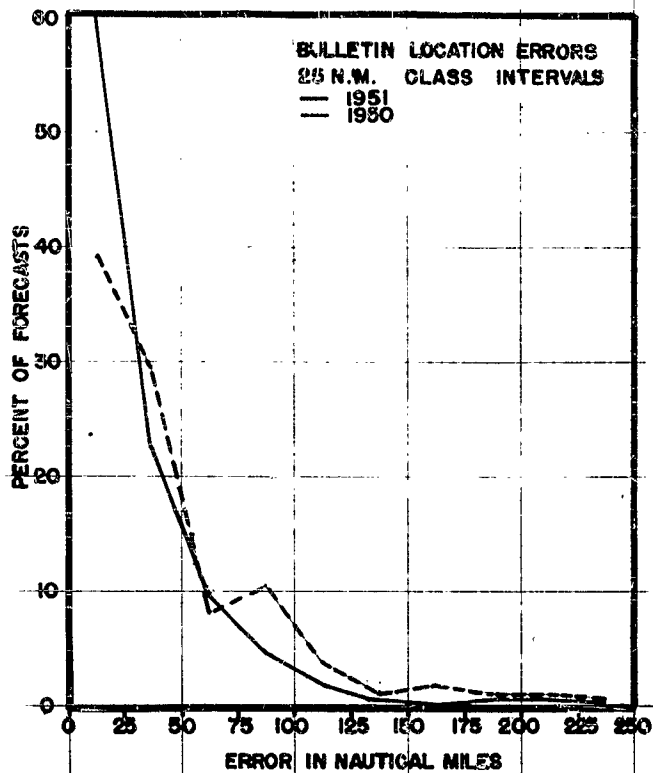


ERROR GRAPH

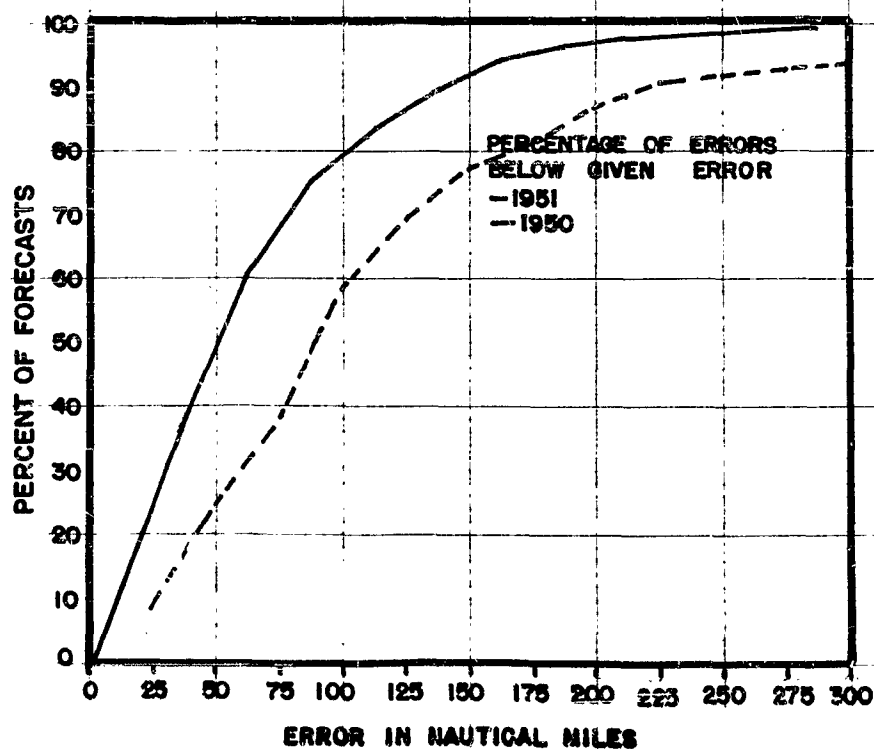
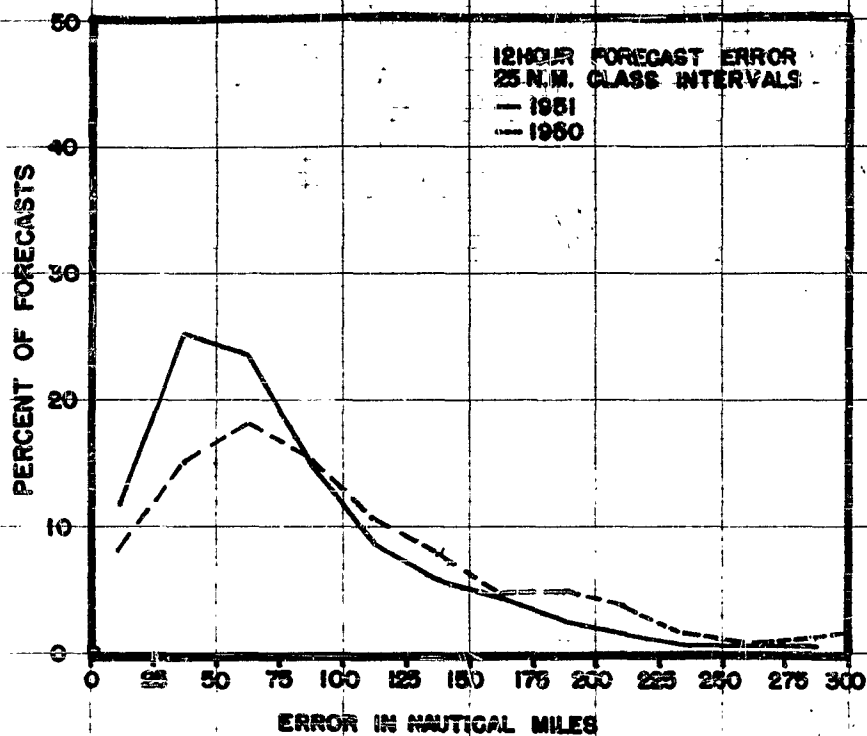
1949 TROPICAL CYCLONES



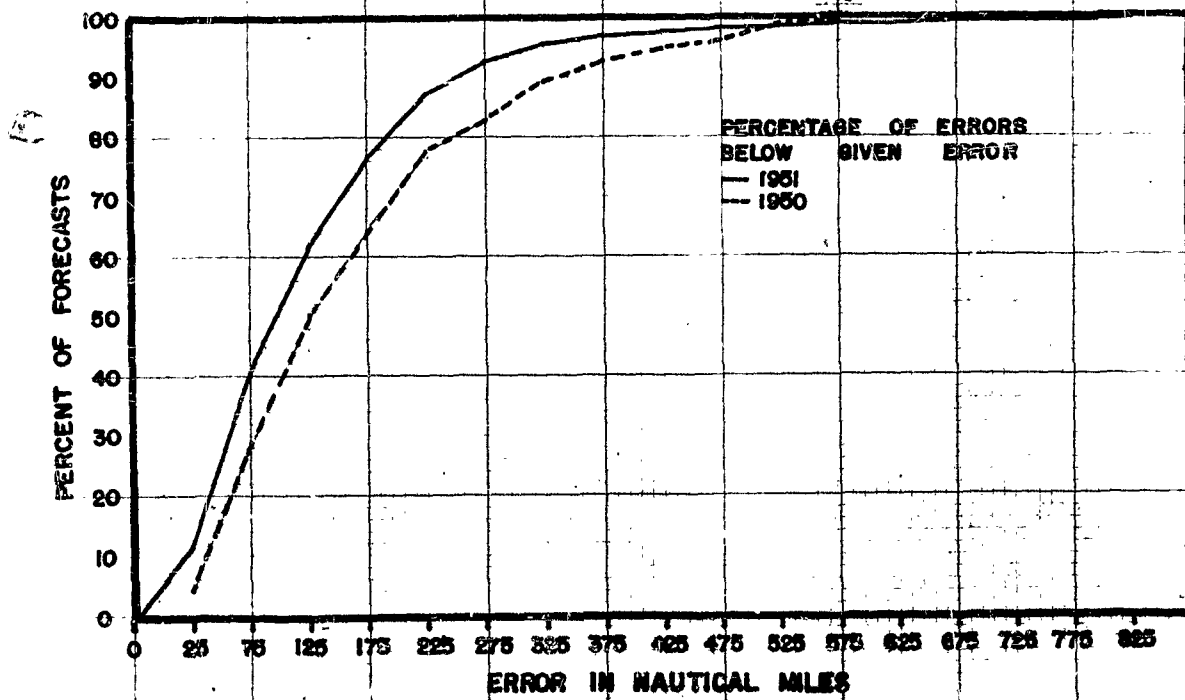
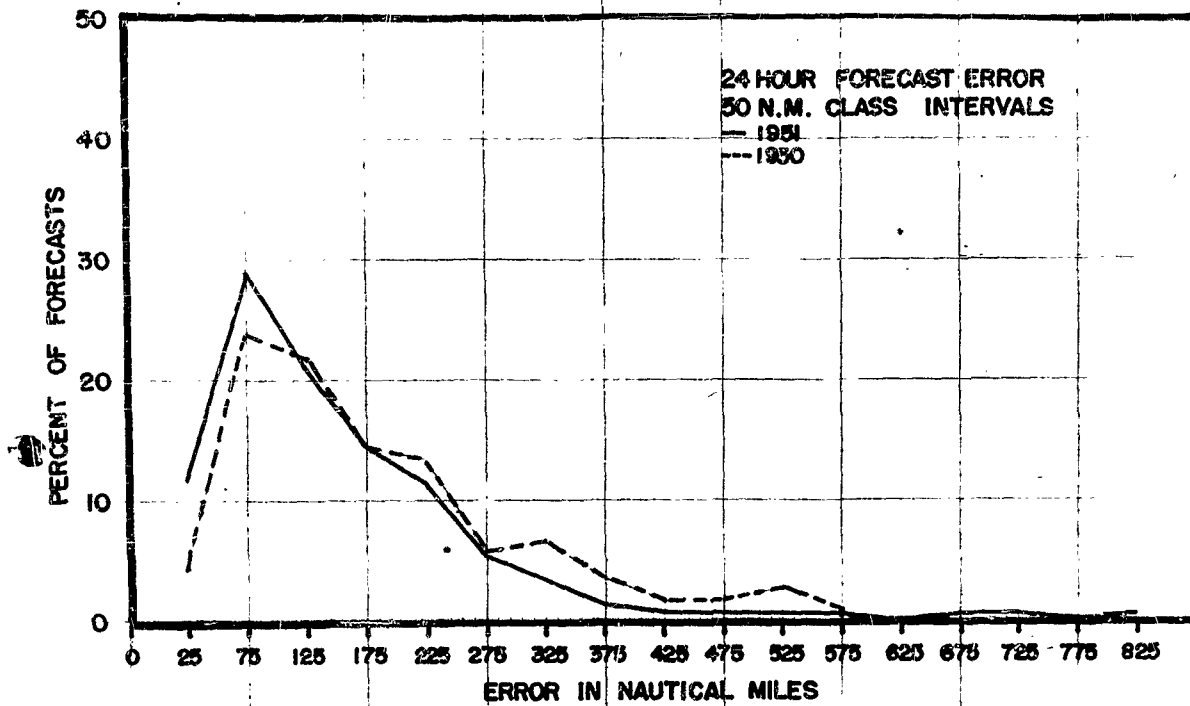
DISTRIBUTION GRAPH BULLETIN LOCATION ERRORS



DISTRIBUTION GRAPHS 12 HOUR FORECAST ERRORS

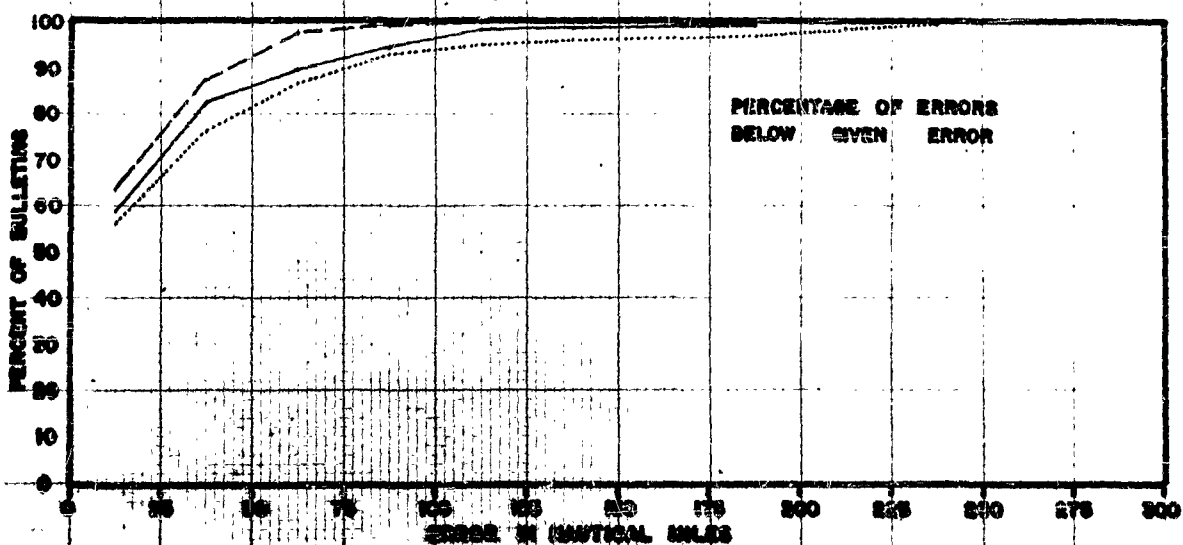
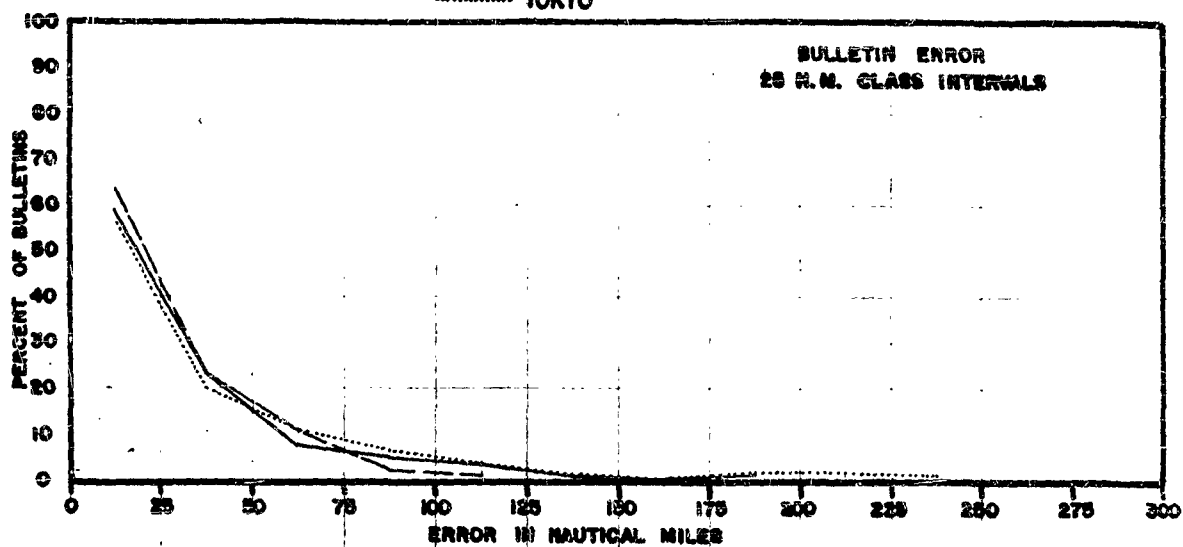


DISTRIBUTION GRAPH 24 HOUR FORECAST ERROR



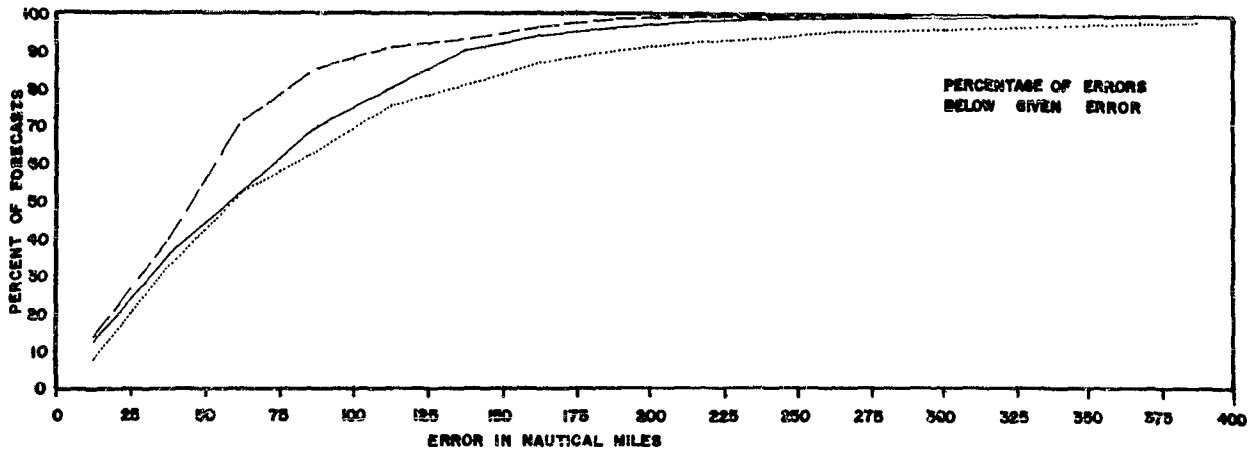
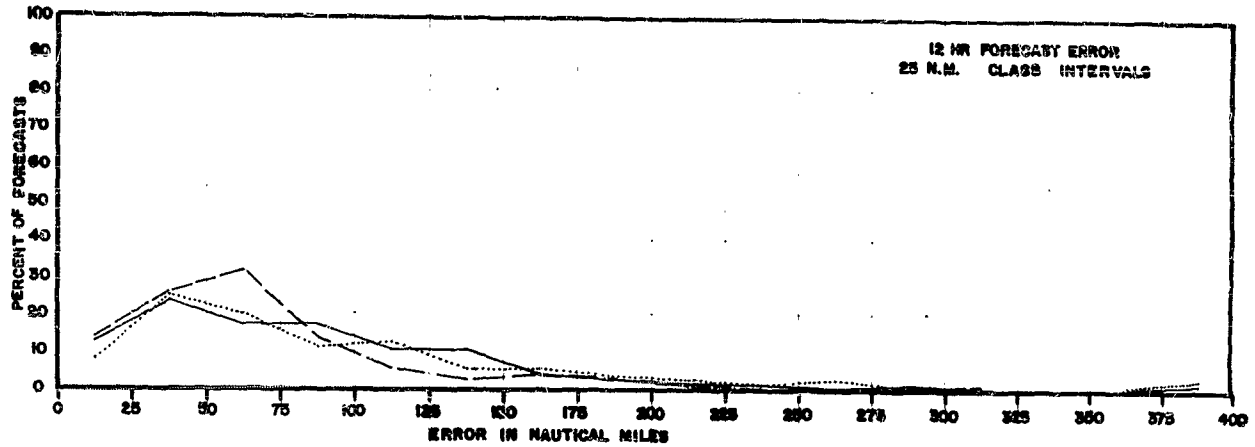
DISTRIBUTION BULLETIN ERRORS
FOR INDIVIDUAL NETWORK UNITS

— GUAM
- - - CLARK
..... TOKYO



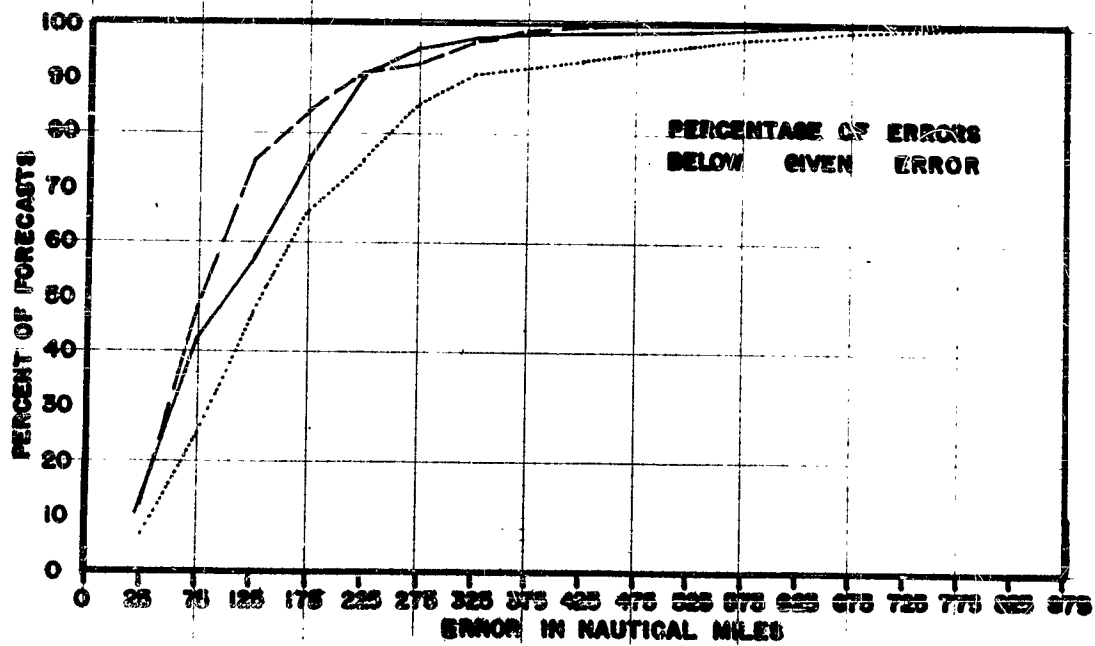
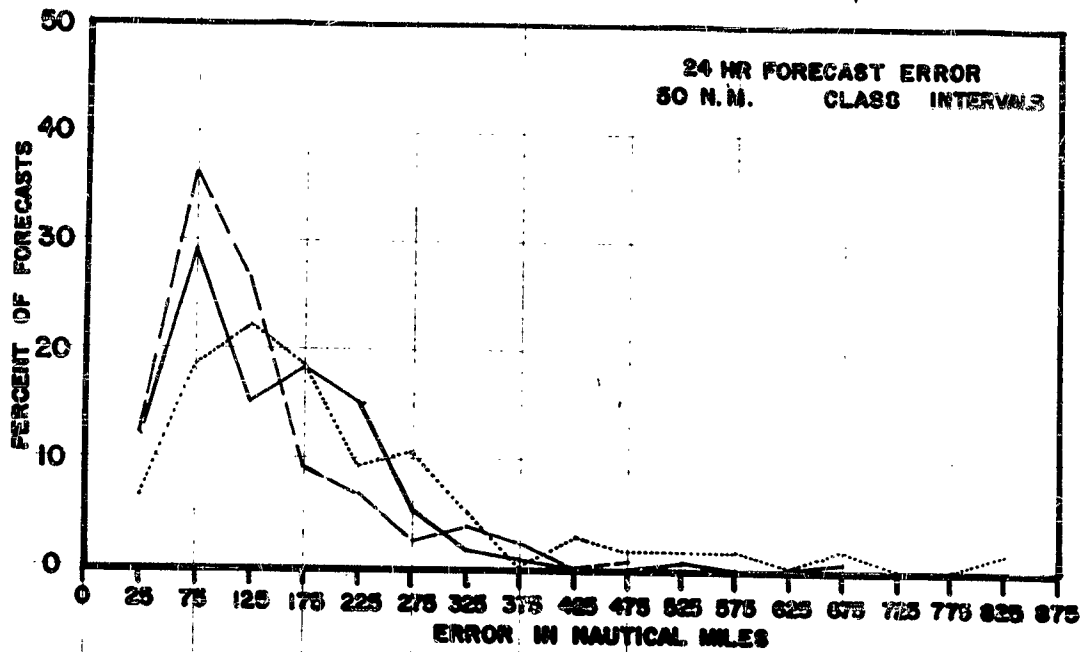
DISTRIBUTION 12 HOUR FORECAST ERRORS
FOR INDIVIDUAL NETWORK UNITS

— GUAM
— CLARK
— TOKYO



DISTRIBUTION 24 HOUR FORECAST ERRORS FOR INDIVIDUAL NETWORK UNITS

— GUAM
 - - - CLARK
 TOKYO



COMPARISON OF

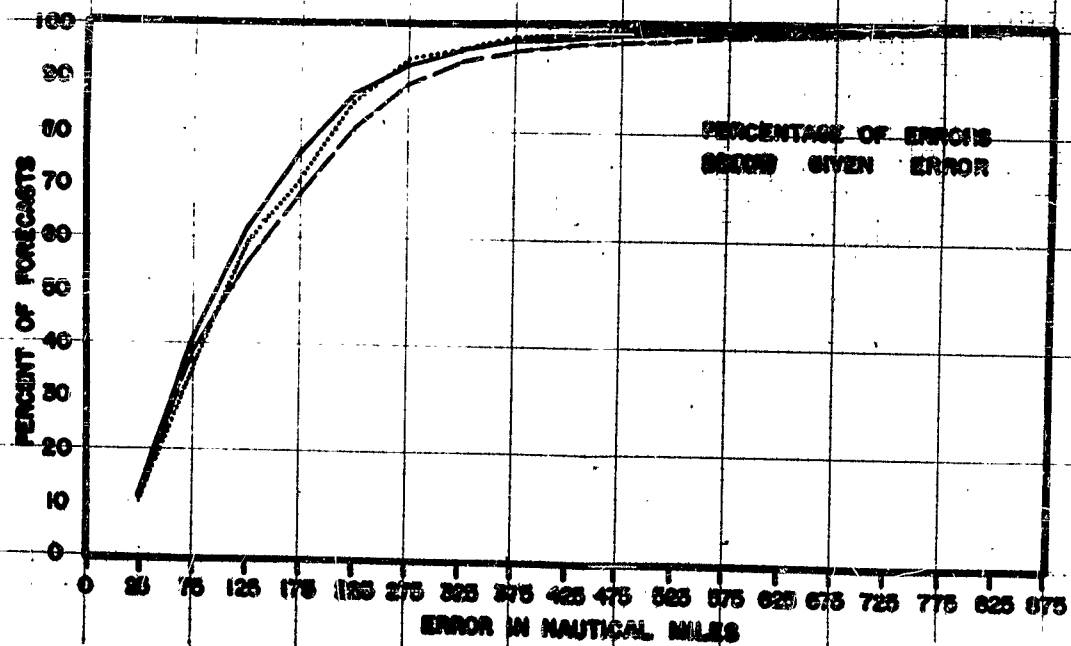
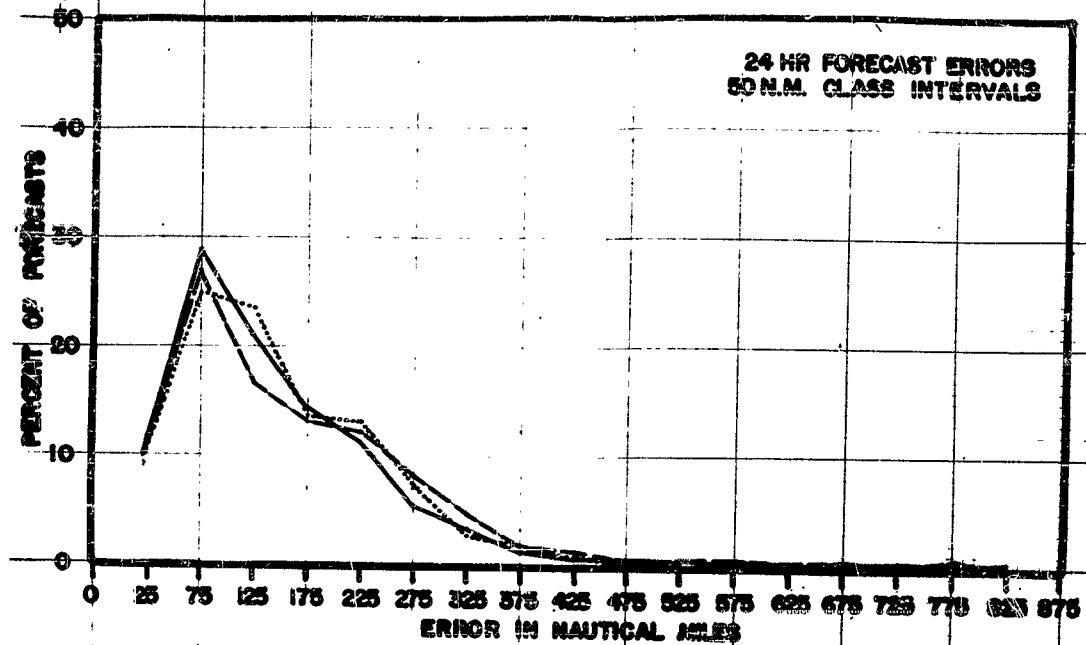
ACTUAL FORECAST - EXTRAPOLATION - CLIMATOLOGY

	24-Hour Forecast Error	24-Hour Extrapolation Forecast Error	24-Hour Climatology Forecast Error
Georgia	125	195	140
Hope	315	245	155
Iris	150	210	190
Joan	205	230	220
Kate	150	210	190
Louise	70	90	110
Marge	130	140	115
Nora	120	145	160
Ora	135	140	145
Pat	230	320	300
Ruth	140	155	165
Sarah	275	245	105
Thelma	185	395	210
Vera	-	-	-
Wanda	125	115	155
Amy	130	135	140
Babs	210	190	150

All figures in nautical miles

**DISTRIBUTION GRAPHS
COMPARING ACTUAL-EXTRAPOLATION-CLIMATOLOGY
24 HOUR FORECAST ERRORS**

----- ACTUAL
----- EXTRAPOLATION
----- CLIMATOLOGY



D. COMPARISON WITH PREVIOUS YEARS

In considering operation of the Network one should compare the occurrence and behavior of tropical cyclones during the 1951 season with that of previous seasons. It has often been said that there is no such thing as a normal typhoon season and that the behavior of individual tropical cyclones varies greatly from the averages. It is true that averages do not describe tropical cyclone behavior adequately, but this is quite often true any time an arithmetic mean is used to describe a phenomenon. Even the most reliable averages are not bases for predicting the value of the next individual item. They must be used, however, to describe the probable central tendency of a group, and, if chosen wisely and used judiciously, they can be of great value in the presenting of summaries or estimating future behavior.

It is the purpose of this section to give a general picture of the 1951 typhoon season, and compare this with other years to see if any trends may be established.

Seasonal Distribution

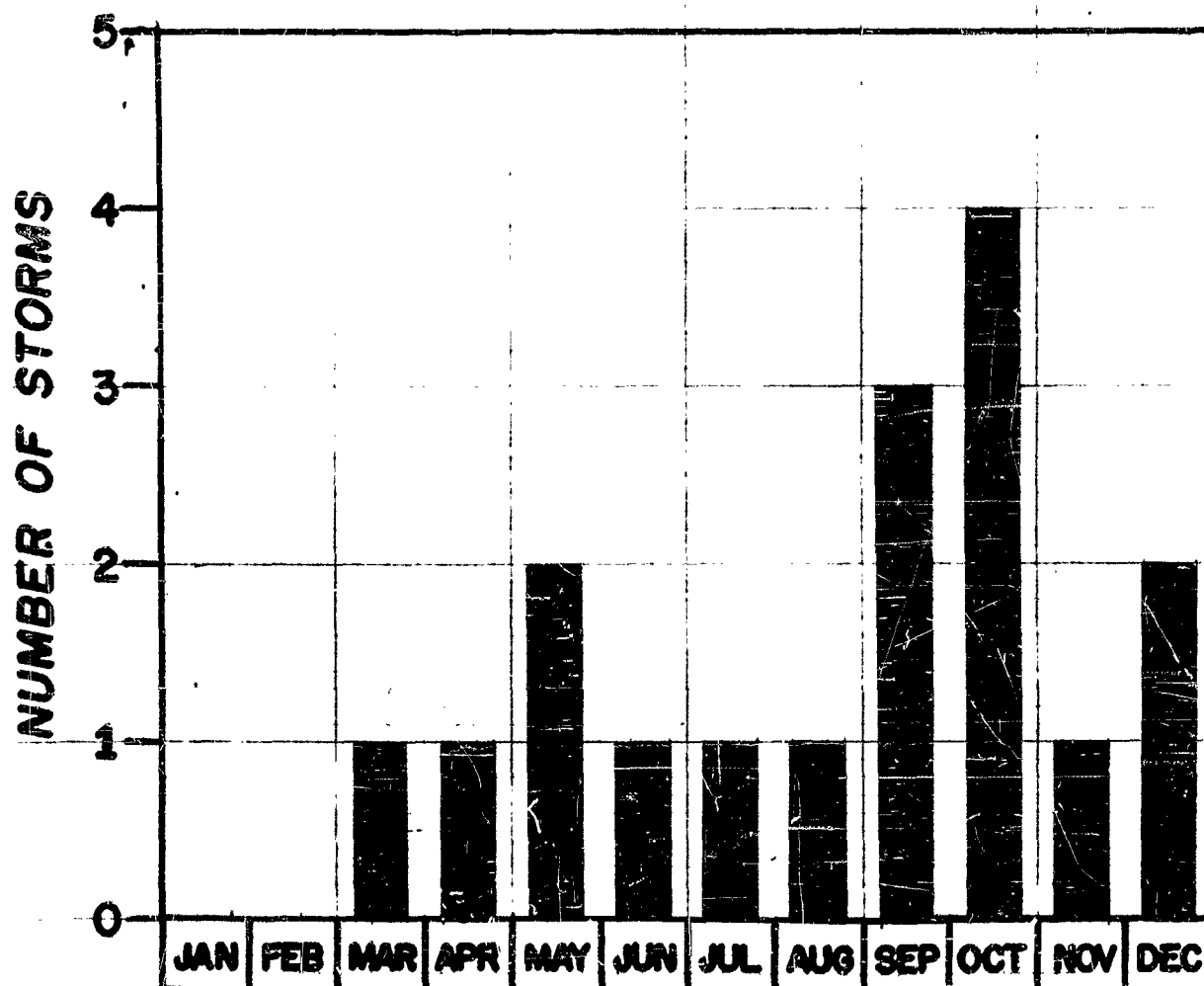
Included on page 52 of this report is a chart showing dates of occurrence, number of bulletins issued, and number of reconnaissance fixes obtained for each individual tropical cyclone. From this a distribution graph of the number of storms per month was made, page 53. In making this graph tropical cyclones which occurred during the last part of the month and the first part of the following month were considered to have occurred in that month in which the greater portion of the typhoon occurred. In making comparisons, two groups of historical data were used: data from 1905 - 1936 inclusive and from 1945 - 1950 inclusive. The main reason for dividing the data into two groups was because of the manner of collection. For the period 1905 - 1936 main sources of data were surface vessels and land reporting stations. Since 1945 these sources have been augmented by aerial reconnaissance. It is of interest to compare the 1951 season with both groups, then to compare the two groups, with the 1951 season included, to see if there are significant differences.

In comparing distribution of tropical cyclones during the 1951 season with the two groups of historical data, little, if any, significant variation from the normal was noted. None with surface winds in excess of 45 knots were reported during January or February. There was only one per month for both March and April. These are all as might be expected during the first four months of the year, for it is indicated by historical data that one tropical cyclone or less per month may be expected from January through April. May and June were quite normal with two being experienced during May and one during June. Historical data indicate that from one to two tropical cyclones with surface winds in excess of 45 knots may be expected during either of these months. There was somewhat less activity than might be expected during July and August. Instead of from three to four, there was only one each month. Season maximum for 1951 occurred during October rather

<u>NAME</u>	<u>DATES</u>	<u>NO. BUL.</u>	<u>NO. FIXES</u>
Georgia	21 Mar - 25 Mar	18	12
Hepe	18 Apr - 20 Apr	10	5
Iris	30 Apr - 12 May	50	31*
Joan	8 May - 11 May	13	7
Kate	29 Jun - 2 Jul	15	7*
Louise	27 Jul - 1 Aug	23	7
Marge	11 Aug - 24 Aug	53	24
Nora	31 Aug - 3 Sep	13	6*
Ora	16 Sep - 21 Sep	22	10*
Pat	25 Sep - 27 Sep	9	1
Ruth	9 Oct - 15 Oct	26	14
Sarah	23 Oct - 27 Oct	16	3
Thelma	27 Oct - 1 Nov	19	7
Vera	31 Oct - 1 Nov	5	0
Wanda	18 Nov - 25 Nov	30	9
Any	3 Dec - 17 Dec	58	25
Babs	11 Dec - 16 Dec	20	7
	TOTAL	400	165

*Fixes obtained prior to first Bulletin

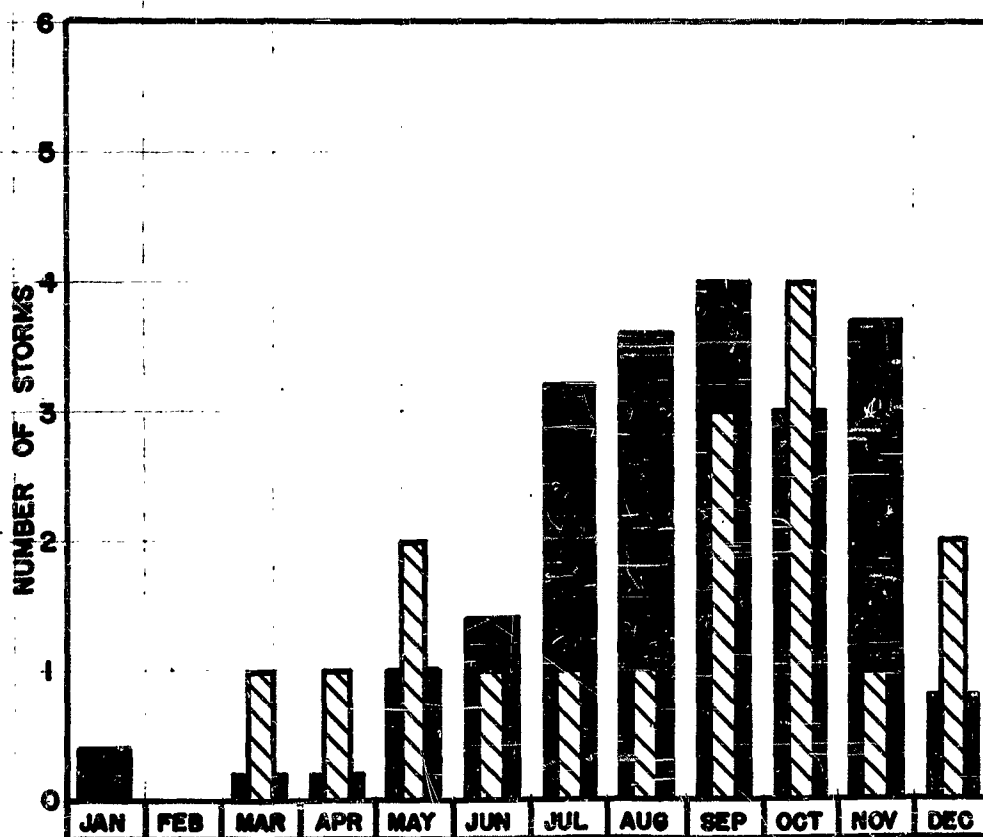
**DISTRIBUTION OF TROPICAL CYCLONES
IN THE WESTERN NORTH PACIFIC
1951**



SEASONAL DISTRIBUTION OF TROPICAL CYCLONES
IN THE WESTERN NORTH PACIFIC

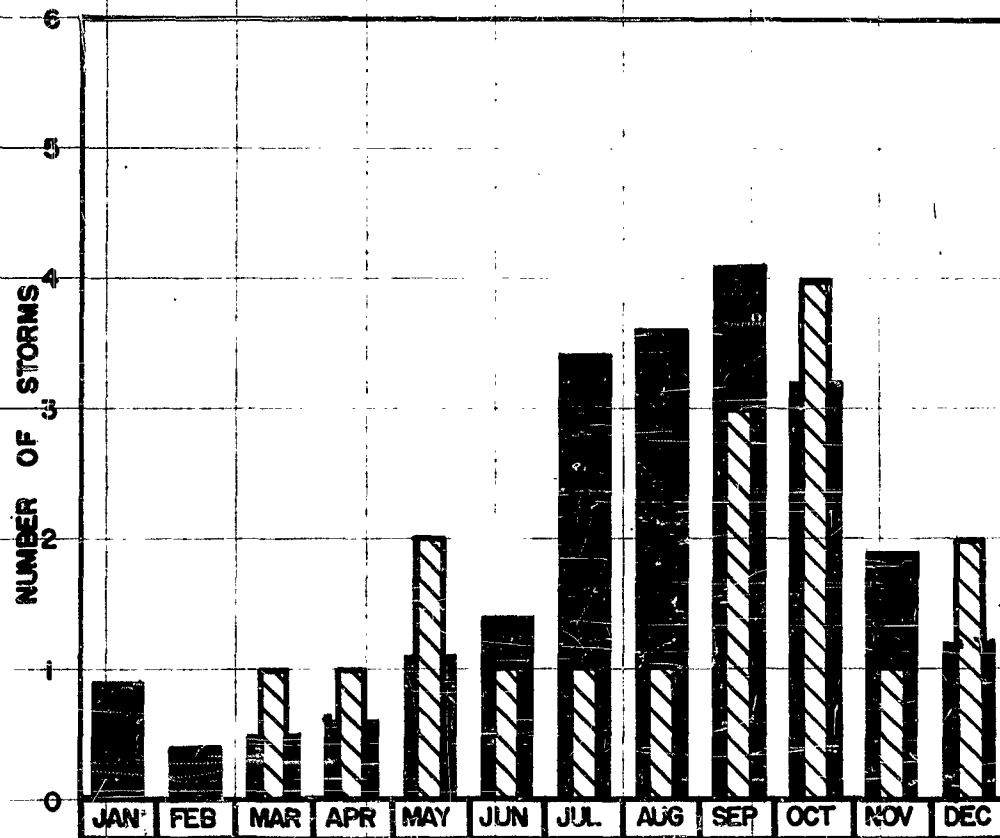
▨ — 1951

■ — 1945-1950 INCLUSIVE



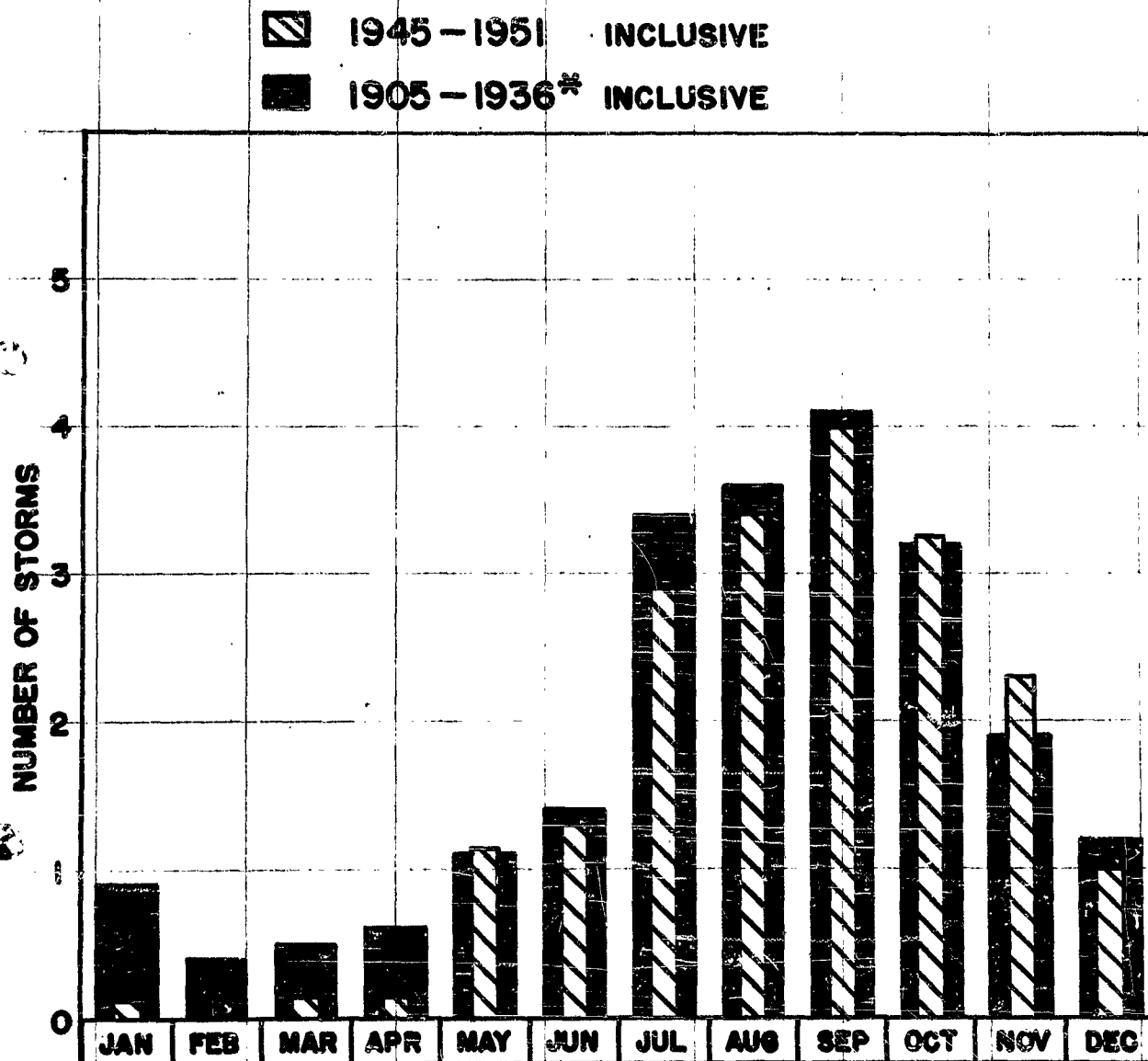
SEASONAL DISTRIBUTION OF TROPICAL CYCLONES IN THE WESTERN NORTH PACIFIC

 1951
 1905-1936* INCLUSIVE



* U.S. ARMY AIR FORCES, WEATHER DIVISION, WEATHER AND CLIMATE OF CHINA 1945, PAGES 27-47

SEASONAL DISTRIBUTION OF TROPICAL CYCLONES IN THE WESTERN NORTH PACIFIC



* U.S. ARMY AIR FORCES, WEATHER DIVISION, WEATHER AND CLIMATE OF CHINA 1945, PAGES 27-47

than September. However, this is not considered to be a marked departure from the normal, as the average for September is four per month and that for October between three and four. So, there are years in which September may be the month of maximum occurrence and years in which the maximum will occur during October. November and December were, also, quite normal. Perhaps the most unusual thing about December was not the number of typhoons which occurred, but the length and severity of a typhoon which did occur during that month. All in all, then, as far as the distribution of tropical cyclones is concerned, 1951 was a normal year.

The two groups of historical data with 1951 tropical cyclones added in the 1945 - 1951 inclusive group were compared, page 56. The same general features are shown by both groups with minimum tropical cyclone activity occurring during the first four months of the year and maximum activity occurring during August, September, and October. There are some differences, however. During the past seven years fewer tropical cyclones with surface winds in excess of 45 knots have occurred during the first four months of the year than did occur during the 32 year period 1905 - 1936 inclusive. A few more tropical cyclones did occur during October and November during the 1945 - 1951 period than the 1905 - 1936 period. These slight differences might be explained by the shorter period of sampling.

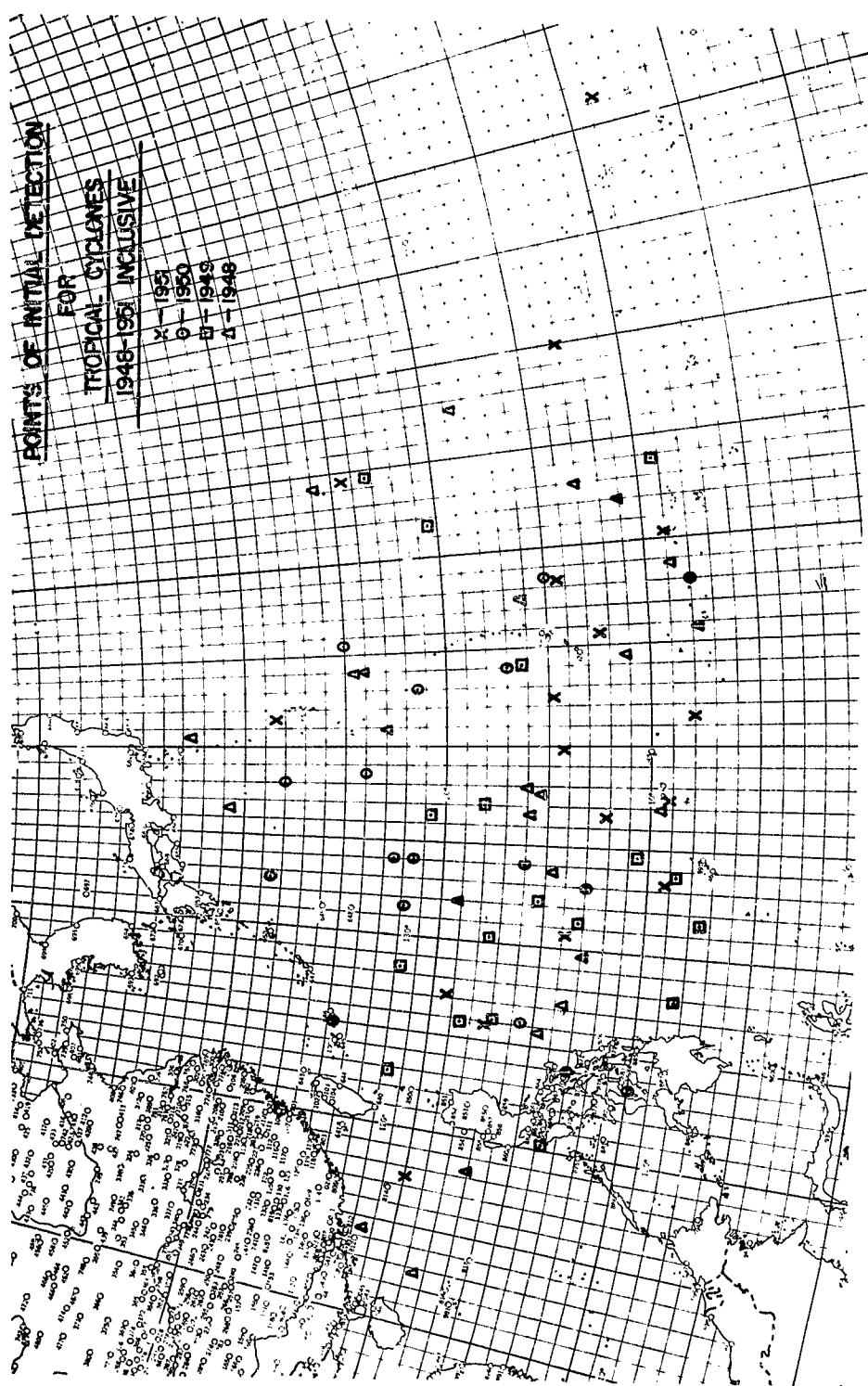
Areas of Formation and Intensification

The great majority of tropical cyclones originate in areas where both surface and upper air data are scarce. Since World War II, aerial reconnaissance has been of great help in the early detection of tropical disturbances. For this reason, areas of formation for those tropical cyclones which developed during 1951 are compared with the areas of formation for tropical cyclones since 1948.

A chart showing the points of initial detection for all tropical cyclones occurring during the period 1948 through 1951 is included in this report, page 58. As can be seen by inspection of this chart, the points of initial detection are scattered over a wide area. The averages for these are as follows:

Year	Av Latitude	Av Longitude
1951	14.6N	141.5E
1950	19.1N	135.8E
1949	15.7N	134.5E
1948	17.4N	138.1E
4 Year Average	16.8N	137.7E

Median values are as follows:



Year	Median Latitude	Median Longitude
1951	13.9N	141.5E
1950	21.5N	134.0E
1949	16.7N	131.8E
1948	16.0N	138.0E
4 Year Median	16.0N	136.7E

During each year the median and mean values agreed quite well. As can be seen, it is rather difficult to describe any one small area in which tropical cyclones intensify. (It is assumed that most of the tropical cyclones were detected soon after intensification during the period 1948 through 1951.) It does appear from inspection of the above tables that during 1951 intensification occurred farther south and farther east than during any of the other three years.

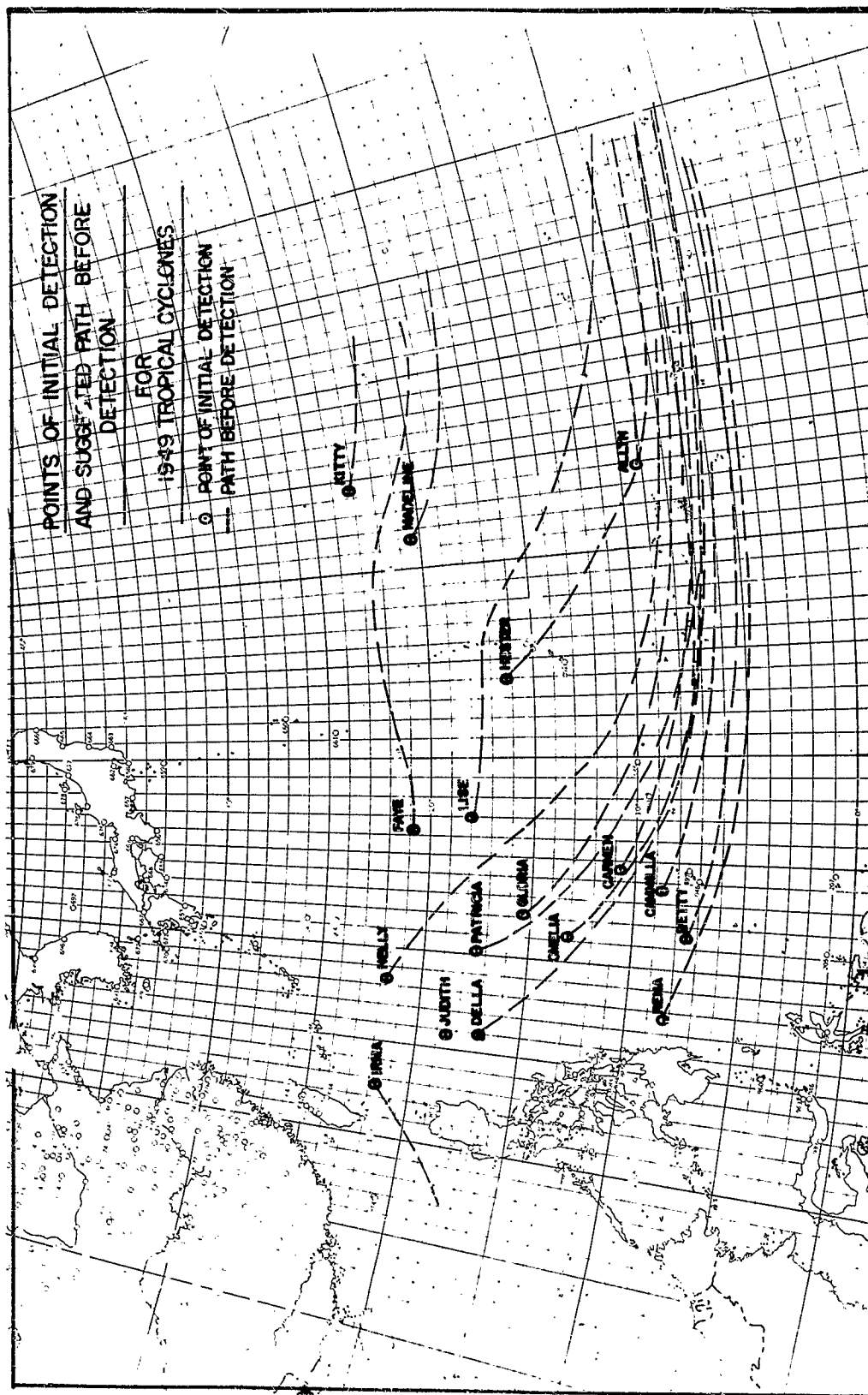
Although tropical cyclones do not have a small, definable area of intensification, there appears to be a source region near Kwajalein for tropical disturbances. Many of the tropical cyclones which became well developed typhoons during 1949, 1950, and 1951, developed from easterly waves or vortices which can be traced back to this area. The charts on pages 60 through 62 show the suggested path, prior to intensification, for those tropical cyclones occurring during the period 1949 through 1951 that could be traced back to their area of origin. Unfortunately not all could be. As can be seen by examination of these charts, many of the initial disturbances did come from the area near Kwajalein. This does not necessarily mean that the initial disturbance originated in that area, but they did at least pass through the area. The actual area of origin may be farther east. However, not enough data is received from the area east of Kwajalein to determine whether this is true or not. Normally it is not until they pass that station that these disturbances can be detected.

These initial disturbances intensify as they move into the area west of Guam, although some attain typhoon intensity before reaching Guam. During 1950 several of the disturbances, while still in the vortex stage, intensified while recurving. During 1951 most of the disturbances intensified prior to recurvature. This is much the same as occurred during 1949.

It appears in comparing areas of formation for 1951 tropical cyclones with other years that 1951 was a quite normal season. Most of the tropical cyclones developed from disturbances in the easterlies which passed through the same areas as in previous seasons.

Speed of Movement

Various average speeds of movement were computed for all 1951 tropical cyclones. These averages compare with averages for other years as follows:



	1949	1950	1951
Before recurvature	10.5	10.0	9.5
During recurvature	9.5	9.5	9.0
After recurvature	16.0	19.0	20.0
Overall average	12.0	12.0	12.0

In making these comparisons, average speeds for all three years were computed in the same manner and rounded off to the nearest .5 knot. There is an appreciable difference between the averages included here for 1950 tropical cyclones and those averages published in the 1950 Annual Report. The averages used here have been rechecked and are believed to be correct.

The range of speeds for 1951 was from nearly stationary to above 30 knots. The same wide range has been exhibited by tropical cyclones of other years.

Intensity

All tropical cyclones during the 1951 season attained typhoon intensity. Four of these Georgia, Hope, Joan, and Amy dissipated while still over tropical waters. With the exception of Georgia, all of the four had either become stationary or executed small anticyclone loops. After attaining typhoon intensity, the other tropical cyclones maintained their intensity until they became extratropical or moved over large land areas.

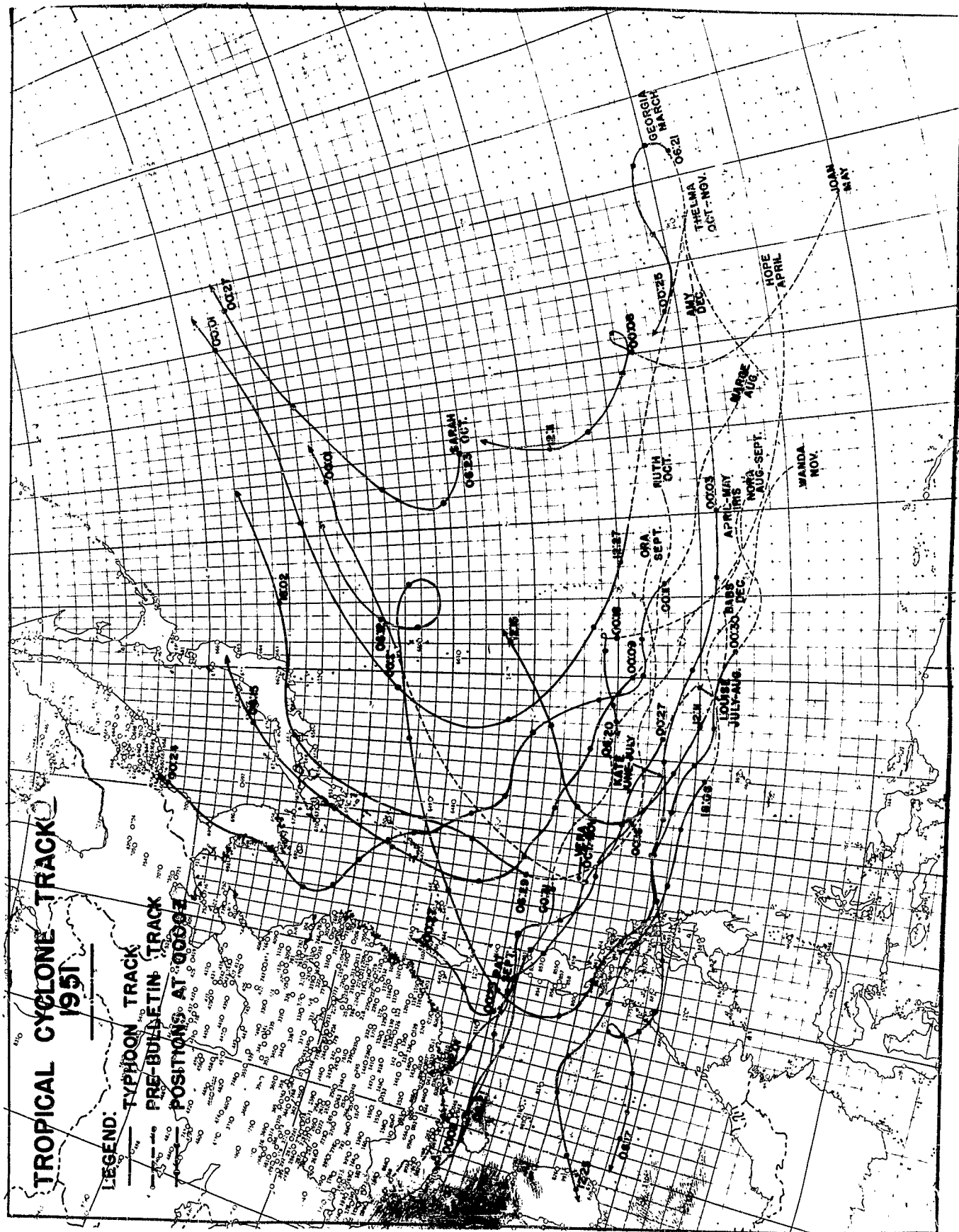
Direction of Movement

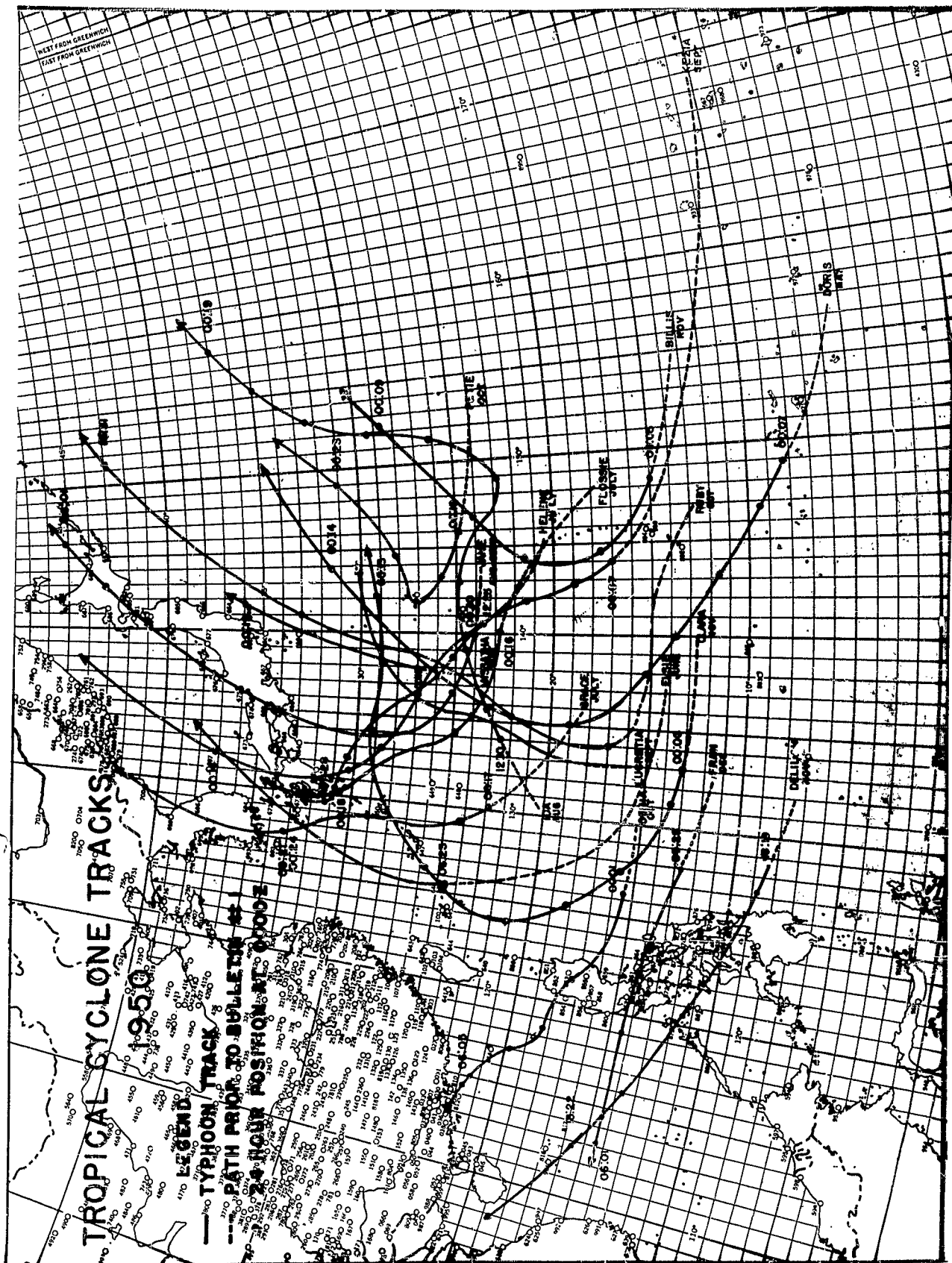
Direction of movement, although varied, was not much different from that during other seasons. Charts, pages 65 through 67, show the tracks of 1949, 1950, and 1951 tropical cyclones. Some of the tracks along which the various tropical cyclones moved during 1951 gave evidence of a type of oscillatory motion. There is nothing different in this from that of previous years, as reconnaissance fixes have often indicated this type of movement. During the 1951 season an effort was made to draw the best path that satisfied all of the fixes on a particular tropical cyclone. In previous years a mean path has been drawn. The fact that such oscillatory paths have been drawn by the Post Analysis Board this past season does not necessarily mean that they do behave in this manner. However, it is the opinion of the present Post Analysis Board members that tropical cyclones do deviate slightly from the mean path.

Also, during 1951, four of the tropical cyclones appeared to loop anticyclonically. This has occurred during other seasons, and has always presented a difficult forecasting problem, for there is, as yet, no known accurate method for predicting such a phenomenon.

Only four of the tropical cyclones during 1951 did not recurve or partially recurve. Fern and Hope were in advanced stages of recurvature when first detected. Both of these looped, then quickly dissipated. Georgia curved cyclonically, rather than anticyclonically, but presented the same forecasting problem as anticyclonic recurvature. Kate was in an advanced stage of recurvature before being detected as a typhoon. Amy began to recurve, was blocked during recurvature, then became nearly stationary and moved southwestward. Much the same problems arose from recurvature during 1951 as during the 1949 and 1950 seasons.

The following section includes a short narrative of each of the tropical cyclones which occurred during 1951.





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E. NARRATIVE HISTORIES

GEORGIA

21 - 25 March 1951

(18 Bulletins)

The 1951 typhoon season was ushered in with the arrival of Tropical Cyclone Georgia. Reports from a routine Vulture George reconnaissance flight on 17 March indicated the existence of a definite cyclonic circulation near 3 degrees north 158 degrees east. From this position it moved northeastward passing approximately 20 miles south of Kwajalein at 0800Z, 20 March, giving that station gusty surface winds of approximately 60 knots. Forecasters at Kwajalein sent a message to Andersen Weather Central. Tropads were then initiated. When reconnaissance arrived in the suspected area of 21 March, a typhoon with winds in excess of 100 knots was found. Typhoon bulletins were initiated by Andersen Weather Central naming this tropical cyclone Georgia. At the time of detection, Georgia was moving northeast. This northeastward movement continued until the tropical cyclone reached a position near 9 degrees north 171 degrees east. At this position Georgia curved back toward the west with a radius of recurvature of approximately 90 nautical miles. Moving westward, the path that Georgia took nearly paralleled the path along which it had moved before recurving. As the tropical cyclone approached Eniwetok it began dissipating rapidly and by 25 March it was deemed to be no longer operationally hazardous.

HOPE

18-20 April 1951

(10 Bulletins)

Early in the month of April a chain of small vortices was noted developing near 4 degrees north 170 degrees east. From one of these small vortices Hope later developed. Analysis of reports from a routine Gooney Dog flight indicated a vortex near 4.5 degrees north 163 degrees east at 0000Z 10 April. Other reports from normal Gooney reconnaissance flights indicated a westward movement by this vortex. By 12 April, it had moved inside the normal Vulture George track. Tropads were initiated on 17 April by forecasters at Andersen Weather Central because of the rapid deterioration of weather noted at Guam. The 54th Strategic Reconnaissance Squadron was requested to reconnoiter the area. A storm was found centered near 15 degrees north 142.5 degrees east. Andersen Weather Central initiated bulletins on Hope which was at that time in the process of recurving. Soon after the second fix, which was obtained at 180600Z, Hope became nearly stationary and executed a small anticyclonic loop. This was accomplished in less than 24 hours. After looping, rapid dissipation occurred as the storm moved first westward then west-southeast and within 48 hours it was considered to be no longer dangerous.

IRIS
30 April - 12 May 1951
(50 Bulletins)

The third storm to occur in the 1951 typhoon season was Iris which, during its 13 day's existence, moved some 4200 nautical miles and established new records for number of bulletins issued and number of reconnaissance fixes obtained. When reports from a surface vessel near 6.5 degrees north 144.5 degrees east indicated winds in excess of 35 knots, Tropads were initiated by Andersen Weather Central and reconnaissance requested for 30 April. A tropical storm was found centered near 8 degrees north 141.5 degrees east at 300215Z. Maximum surface winds at that time were estimated to be 55 knots in all quadrants. Iris moved along an oscillatory path from the position of initial penetration until after crossing the Philippine Islands. After entering the South China Sea the typhoon began to recurve to the northeast. The path became very regular after recurvature had occurred. A problem did arise concerning the transfer of forecast responsibility in that this was also a period of transition from the 1950 to the 1951 Typhoon Warning Service SOP. Clarification as to whom to transfer forecast responsibility was received from Headquarters, 2143d Air Weather Wing. The 1951 SOP was followed for transfer of forecast responsibility. Iris moved northeast at approximately 25 knots through Tokyo Weather Central's area of responsibility until 10 May. Then one of the most difficult forecasting problems was encountered for, at this point, Iris began looping. This was one of the four tropical cyclones to do this during the 1951 season. Rapid dissipation occurred after looping, and the final bulletin was issued on 12 May at 0600Z.

JOAN
7 - 11 May 1951
(13 Bulletins)

Normally tropical storms in the Marshall Islands are a rarity. However, during the 1951 season two storms affected these islands; first was Georgia, the second Joan. Both presented, during their brief existence, large forecast problems. Joan, when first positive evidence of a tropical storm's existence was obtained, was in a well advanced stage of recurvature. First positive evidence of Joan's existence was given by an Air Force fix at 072230Z. Within 36 hours Joan completed an anticyclone loop and again began recurving. However, dissipation occurred within 30 hours after looping and the final bulletin was issued at 0000Z, 11 May.

KATE
29 June - 2 July 1951
(15 Bulletins)

Progress of a vortex which was originally detected near 7 degrees north 159 degrees east at 0600Z on 17 June was followed as this disturbance moved westward passing some 250 miles south of Guam. By 25 June reports from aircraft flying between the Philippines and Guam indicated that a tropical storm existed somewhere south of that route near 139 degrees east

longitude. Andersen Weather Central began issuing Tropads and requested that the 54th Strategic Reconnaissance Squadron investigate the suspected area. An aircraft departed Guam on 26 June, and, upon arrival in the suspected area, found a cyclonic circulation with maximum winds of 35 knots. The center was near 12 degrees north 134 degrees east. It was decided to carry this area on Tropads. Late on 28 June, reports from surface vessels indicated that the vortex had further intensified. Again the 54th Strategic Reconnaissance Squadron was requested to investigate the area. This time a typhoon with maximum winds of 75 knots was found centered near 19.2 degrees north 127 degrees east at 290400Z. It was at this time in a far advanced stage of recurvature. No particular difficulties were encountered in forecasting the storm's speed or direction as it moved north-northeastward toward Kyushu. Kate moved through Kyushu along the north coast of Shikoku decreasing in strength then curved toward the east. Late on 2 July, as a tropical storm, Kate moved out to sea. Within 12 hours maximum winds decreased to 40 knots.

LOUISE

27 July - 1 August 1951
(23 Bulletins)

Easterly wave 07083 was watched with a great deal of interest as it passed by Guam on 25 July at 0600Z. Reports from Ulithi indicated the presence of a tropical disturbance north-northeast of that island at 260600Z. Strong northwest winds and pressure falls at 6.1 millibars during a 9-hour period were noted. The 54th Strategic Reconnaissance Squadron investigated the area on 27 July and they found a fully developed typhoon centered near 12.2 degrees north 136.4 degrees east at 270105Z. Bulletins were initiated by Andersen Weather Central assigning the name Louise to this typhoon. The path along which this tropical cyclone moved was very interesting as it gave good evidence of oscillatory movement. Louise entered the coast of Northern Luzon on 30 July, however, winds of typhoon intensity began lashing Isabela Province late on 29 July. Although the stay of this typhoon was brief, the damage was great and by the time Louise had moved into the South China Sea on 31 July, a wide swath of devastation had been cut through Northern Luzon. Serious damage was done to crops and property. By 1800Z Louise entered the China coast near Hong Kong at tropical storm intensity. Dissipation occurred rapidly.

MARGE

11 - 24 August 1951
(53 Bulletins)

One of the longest typhoons during this season was Marge. In all, 53 bulletins were issued after vortex 08053 attained tropical storm intensity. Good evidence was given of an oscillatory movement. When approximately 300 miles west-southwest of Guam what at first appeared to be recurvature occurred, but instead Marge moved northwestward and continued in that direction along an oscillatory path until 21 August. At that time, Marge was near 32 degrees north 123 degrees east. Here slight recurvature occurred as the storm moved along the west coast of

Korea, then crossed that peninsula between 28 degrees and 30 degrees north latitude. By 24 August, the cyclone was deemed to be non-hazardous operationally so the final bulletin was issued by Tokyo Weather Central.

NORA

31 August - 3 September 1951
(13 Bulletins)

Another storm which gave good evidence of oscillatory movement was Nora which finally attained typhoon intensity on 31 August. Vortex 08063, which was first detected in the vicinity of Truk on 23 August, was kept under constant surveillance. On 27 August, because of the deterioration of weather near and to the west of Guam, it was requested that the 54th Reconnaissance Squadron investigate the area next day. A thorough search was made and a cyclonic circulation of moderate intensity found. On 30 August, reports from a surface vessel near 18.3 degrees north 129.5 degrees east indicated intensification. Bulletins were initiated by Clark and matters progressed in a routine manner as Nora proceeded west-northwestward across the northern tip of Luzon. Upon entering into the South China Sea on 1 September, Nora, which had decreased in intensity while moving across the Philippines, both intensified and accelerated. By 3 September, the typhoon was rapidly approaching the Chinese coast and decreasing in intensity. Upon entering into China rapid dissipation occurred.

ORA

16 - 21 September 1951
(22 Bulletins)

The disturbance from which Ora developed was first carried on easterly wave bulletins as Easterly Wave 09032. A passage was noted at Guam on 12 September. On 16 September, although maximum winds found by reconnaissance were 35 knots, conditions were favorable for intensification so Bulletin 1 was issued forecasting winds at 60 knots within the next 24 hours. Reconnaissance verified this forecast the next day. The track of Ora was quite similar to that of Nora. As Ora approached the Philippines there was a tendency to recurve, however, a large oscillation resulted instead with the typhoon turning westward passing north of Luzon on 18 September. No damage was done to populated areas during Ora's existence. As the tropical cyclone moved through the South China Sea small oscillations were apparent. After the tropical cyclone moved over Hainan, the last bulletin was issued by Clark at 0600Z on 21 September.

PAT

25 - 27 September 1951
(9 Bulletins)

PAT was of short duration dissipating within 48 hours after reaching typhoon intensity. Originally the disturbance from which Pat developed was carried on Easterly Wave bulletins; first as Easterly Wave 09053 then, as Vortex 09014. Easterly Wave 09053 was dissipated at 221800Z because of

a lack of evidence to verify its existence. Later Clark picked up and relocated this wave at 120 degrees east. Slightly later there was evidence of a vortex in the South China Sea which was picked up by Clark and numbered 09014. On 25 September Prata Island reported 63 knot surface winds. Bulletins was initiated by Clark and the 54th Strategic Reconnaissance Squadron requested to investigate the area. After flying all night, the crew located a full-grown typhoon at 0600 local time with winds in excess of 90 knots. This reconnaissance fix was the only one obtained for Pat was moving toward Formosa. Upon moving over that island the typhoon dissipated rapidly and little evidence of its existence was given by the reconnaissance reports next day. It was not possible to fix the center exactly because of the dangerous terrain on Formosa, but the aircraft did circumnavigate that island and found a definite cyclonic circulation with its center somewhere over Formosa. On 28 September, a reconnaissance aircraft which was returning to Guam was diverted to the area and found no indications of a storm existing.

RUTH

9 - 15 October 1951
(26 Bulletins)

Another typhoon which developed from an easterly wave was Ruth. Easterly Wave 10012 of weak intensity was detected passing by Kwajalein at approximately 1500Z on 2 October. As it moved westward toward Guam at 10 knots, it was kept under constant surveillance. Soon after passing south of Guam as a vortex on 8 October, rapid deterioration of the weather at Andersen Air Force Base was noticed. Because conditions were favorable for intensification reconnaissance was requested for 9 October. Upon arrival in the suspected area a tropical storm with winds of 40 knots was found centered near 14.2 degrees north 139.7 degrees east at 082357Z. The decision was made to issue bulletins even though maximum winds were reported to be 40 knots. By the time Bulletin 1 was completed reconnaissance reported winds of 45 knots 75 miles from the center which would have necessitated bulletins anyhow. Within the next 6 hours Ruth intensified to 60 knots. Moving along an oscillatory path toward the northwest, Ruth began recurving on 12 October. On 13 October the typhoon passed slightly west of Okinawa hammering that island with winds of 120 knots. Average speed of movement accelerated from that point on until the tropical cyclone was moving in excess of 25 knots. As Ruth increased in speed and moved along the western edge of the Japanese islands a decrease in intensity was noted. The final bulletin was issued with a valid time of 151200Z by Tokyo as Ruth became no longer operationally hazardous.

SARAH

23 - 27 October 1951
(16 Bulletins)

Sarah was one of three typhoons which were small in size but of great intensity. The first indication of Typhoon Sarah's existence was given by hourly weather reports from Marcus Island. At 0000Z on 23 October, the surface wind at Marcus was reported to be from the north at 33 knots.

Pressure falls in excess of 5 millibars for 24 hours was noted. Forecast responsibility was assigned to Tokyo Weather Central and the first bulletin issued with a valid time of 230600Z. When a 54th Reconnaissance Squadron aircraft had investigated the suspected area, a typhoon of 90 knot winds was located. Sharp recurvature occurred soon after passing Marcus. To add to the difficulty of forecasting, Sarah accelerated to 18.5 knots. Location of the typhoon's center was exceptionally difficult by synoptic analysis because of the extremely small size. Aircraft flying near its center gave little or no indication of a typhoon existing. The Typhoon Warning Service network was completely dependent upon reconnaissance for locating the typhoon's position. The final bulletin was issued on 27 October.

THELMA

27 October - 1 November 1951
(19 Bulletins)

Evidence of a vortex passage was noted by analysis of Kwajalein's time cross-section. The time of this passage was at 240600Z. Further evidence of the vortex's existence was given by analysis of Eniwetok's time cross-sections which indicated that it was south of that atoll at 250600Z. Speed of movement increased from 15 knots to 16.5 knots as the vortex moved west-northwestward toward Guam. While returning to Guam from Wake Island a weather observer of the 54th Strategic Reconnaissance Squadron noted an area of unusually heavy convective cloudiness and precipitation to the south of the course. Upon diverting this flight a small but intense typhoon with winds of 90 knots was found centered at 14.3 degrees north 148.6 degrees east on 27 October. Average speed of movement increased to 20 knots after Thelma had reached typhoon intensity. It was with mixed anxiety that the people of Guam watched the approach of this raging typhoon. Early on Sunday morning, 28 October, Thelma passed nearly over Saipan lashing that island with 90 knot winds, while at Guam, only 120 miles south, little but the usual tropical weather was experienced. At this time the southern quadrants of Thelma were open. As the typhoon continued on northwestward, recurvature began. Soon, after recurving, speed of movement became 30 knots and Thelma rapidly became extratropical. One of the most unusual phenomena noted during Thelma's existence was the typhoon's extremely small size. Perhaps the best indication of its size was given by the fact that on the third mission a veteran weather observer descending to 1500 feet to search for the typhoon, which, at that time, was within 150 miles of his position, did not believe that a typhoon existed for many miles. Within the next 45 minutes winds were noticed to increase rapidly from below 15 knots to above 40 knots. Severe turbulence was encountered within a few brief moments and the aircraft caused to go into a steep bank and descent rapidly. It took the combined strength of both pilots applying full opposite controls to right the plane. The eye was of such small diameter that the aircraft could not remain within it after the penetration had been made.

VERA

31 October - 1 November 1951
(5 Bulletins)

While Thelma was still in existence, a second disturbance which originated approximately 300 miles east of the Philippines developed into tropical storm intensity. With the exception of a few surface vessels and the time cross-section for Iwo Jima little evidence was given of this storm's existence which was named Vera. The first bulletin was issued with a valid time of 010000Z and was based upon reports from surface vessels in the vicinity of Iwo Jima. Speed of movement was quite rapid. Two attempts to fix the center were made by the 56th Strategic Reconnaissance Squadron but no fixes were obtained. By 1 November, no evidence was given of a tropical storm existing so the final bulletin was issued with a valid time of 010600Z.

WANDA

18 - 25 November 1951
(30 Bulletins)

On the basis of analysis of the Yap and Koror time cross-sections Tropads were issued on a disturbance near 9 degrees north 137 degrees east. Valid time of initial Tropad was 1800Z on 17 November. Reconnaissance was dispatched to the area and a fix at 180310Z gave winds of 100 knots. Bulletins were then initiated by Andersen Weather Central assigning the name Wanda to this typhoon which moved west-northwestward toward the Philippines. Some evidence was given of slight oscillatory movement. On 20 November, Wanda entered the west coast of the Philippines. Late on 21 November, Wanda passed into the South China Sea and continued to move northwest until 23 November. At that time a marked deceleration was noted which gave the appearance that the typhoon might possibly recurve. Actually Wanda began moving west-southwest and quickly dissipated. On 25 November, because inflight reports from Saigon indicated rapid dissipation was occurring, a final bulletin was issued with a valid time of 251200Z.

AMY

3 - 17 December 1951
(58 Bulletins)

While on a normal Vulture George flight, which left Guam at 2130Z, 2 December, an alert weather observer noticed that winds were shifting to the east with wind speeds increasing to an estimated 35 knots at the surface. The flight was immediately diverted to investigate the area to the south. At 030040Z, a tropical storm was found centered near 9 degrees north 150.2 degrees east with maximum winds at that time estimated to be 60 knots in the northeast quadrant. Upon boxing this storm it was noted the southern quadrants were weak with winds being no greater than 15 to 20 knots. It is possible that two centers existed during the early stages of Amy. This was indicated by reconnaissance flights Vulture Three, Five and Seven Amy. On Vulture Three Amy, when the morning penetration was made, strongest winds were found to be 45 knots, but, while boxing the storm,

stronger winds were found in the north. Later a second penetration was made and winds of 85 knots were found with the center some 150 miles north-west of the earlier position. Later the weather observer on Vulture Five Amy reported two complete circulations. At 062330Z, the primary center was at 11 degrees 57 minutes north 131 degrees 41 minutes east. A secondary center was reported at approximately 15.9 degrees north 131.2 degrees east. Both centers were determined by use of variable drift winds. Again, on Vulture Seven Amy, evidence was found of two separate systems, when, at first attempt to penetrate Amy, the aircraft apparently went between two centers. By making use of radar a penetration of the secondary circulation was made. This was found to be open in the direction of the primary eye which was then penetrated. At that time, the eye was only 16 miles in diameter and turbulence within it was so severe that accurate instrument readings could not be made. There was little evidence from this time on of two centers existing. The disturbance from which Amy developed was first detected as a vortex which passed nearly over Kwajalein at 0500Z on 29 November. The number 11122 was assigned to that vortex which was kept under constant surveillance as it progressed westward. Initially, the tropical cyclone which attained tropical storm intensity on 3 December, had been moving at 10 knots. On 4 December there was a rapid acceleration to 17 knots. By late 6 December this decreased to 7.5 knots. This average speed of movement continued as Amy approached the Philippines. On 9 December, the typhoon entered the Philippine coast near 11 degrees north 126 degrees east and for the next two days raged through Leyte, Cebu and Panay lashing those islands with typhoon intensity winds leaving a path of devastation in its wake. Late on 11 December, Amy moved off the coast of Palawan leaving many persons killed, injured or homeless. After entering the South China Sea, the typhoon remained nearly stationary just off the Philippine coast for three days. During this time it executed a small loop. Finally, a slow west-southwestward movement was noted. By 17 December, Amy decreased to tropical storm intensity. The final bulletin, which was Number 58, was issued by Clark with a valid time of 170900Z. Thus ended Amy, a typhoon which, during its 15 days existence, established records for number of bulletins issued, 58, and number of reconnaissance fixes obtained, 25.

BABS

11 - 16 December 1951
(20 Bulletins)

While Amy was still raging through the Philippines, another tropical storm developed southeast of Guam near Ulithi. On 10 December, winds of 50 knots were reported on the final leg of Vulture George. The 54th Reconnaissance Squadron was requested to investigate the area southeast of Guam on 11 December. A tropical storm was found near 9.4 degrees north 137.6 degrees east at 110335Z, and was subsequently named Babs. Because of the distances involved and the shortage of aircraft a problem arose in supplying reconnaissance for the two tropical cyclones in existence. However, at all times the 54th Reconnaissance Squadron provided adequate reconnaissance. From the position of the first fix, Babs moved northwestward at 13.5 knots. A deceleration to 8 knots was noted as the tropical cyclone began to recurve. Then, after recurvature, rapid acceleration was observed.

Within 30 hours after recurvature, Babs was moving at a speed in excess of 20 knots and continued to accelerate to above 30 knots. Rapid dissipation occurred as the typhoon moved into an area of strong westerly winds. By 15 December, little evidence of a tropical cyclone existing was found by reconnaissance. The final bulletin was issued by Tokyo Weather Central at 160855Z. Thus ended Babs, which began an Easterly Wave 12022, the last storm to begin during the 1951 season. The 1951 typhoon season actually ended with the dissipation of Amy on 17 December.

F. RECOMMENDATIONS

It appears that the primary weakness in tropical cyclone forecasting has been the low experience level in this field. Usually, a forecaster acquires enough experience in this field to be of real value, then returns to the Zone of the Interior. It is recommended that every effort be made to stabilize the assignment of personnel in this field and attempt to secure personnel who have prior experience in the field. New forecasters can be fed into the system from tropical meteorology schools and from the large number of forecasters with meteorological experience in the tropics although not necessarily in tropical cyclone forecasting. It is recognized that such a program would be a considerable problem in view of the requirements placed upon the Air Weather Service by the current expansion of the Armed Forces.

It is recommended that a Tropical Cyclone Forecasters' School be held prior to the beginning of each "season" to familiarize designated forecasters with theories about causes, structure, and behavior of tropical cyclones in this area. Perhaps a two-week school would be the proper length, with one week devoted to study of the Typhoon Warning SOP and problems in its use. A similar school was held on Guam in 1951 and the benefits derived therefrom are believed to be well worth the man-hours expended. For example, not only was the forecast error the smallest to date in 1951, but the Typhoon Warning Service was almost completely free from the type of procedural errors which plagued it during the 1950 season.

It is recommended that the designated Typhoon Forecasters fly the main air routes adjacent to their stations to familiarize themselves with the normal weather picture in order to better evaluate deviations from the normal state. In addition, it would be advantageous for the Typhoon Forecasters to fly at least one "eye" penetration with one of the reconnaissance squadrons during their indoctrination period.

A great amount of data about tropical cyclones is available at Guam. Much of these data will never be used due to the operational requirements and shortage of personnel for the Post Analysis Board. It is recommended, therefore, that a well-qualified civilian meteorologist be hired and assigned to the Center at Andersen. He would be free from operational requirements and could effectively advise the Post Analysis Board on research problems, recommend data requirements to be requested from the reconnaissance squadrons, etc.

It is recommended that a joint Air Force-Navy Post Analysis Board be established at Guam. This would result in economy of personnel, communications, and materiel in avoiding the existing duplication of effort.

Finally, it is recommended that a Northern Hemisphere analysis at 200 and 700 millibars be transmitted by facsimile to all units of the Typhoon Warning Network in order that the behavior of long waves may be used in forecasting tropical cyclones. These waves play an important role in every phase of a tropical cyclone's life cycle from initial intensification to final decay.